TAMPERE UNIVERSITY OF TECHNOLOGY

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AN APPROACH FOR ISA-95 APPLICATION TO INDUSTRIAL SYSTEMS

Master's Thesis

The subject was approved in the meeting of
the Department of Automation Council
MAY 2012

Examiners: Professor José Luis Martínez Lastra

ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
Master of Science Programme in Machine Automation
He, Dazhuang: AN APPROACH FOR ISA-95 APPLICATION TO INDUSTRIAL SYSTEMS

Master of Science Thesis, 80 pages, 15 Appendix pages
April 2012
Major subject: Factory Automation
Examiner: Professor José Luis Martínez Lastra
Keywords: ISA-95, GUI, B2MML, ERP, MES, UML

During last years software starts to play a significant role in the development of industrial automation systems such as automated production systems. The growth of computational resources of industrial controllers and computers, the communication and information processing capabilities increase. As one of the benefits of this increase of capabilities, it allows the implementation of functionally-rich protocols originally developed by the IT world on the industrial devices and their supportive computer systems. The simplification of network reconfiguration often relies on the ability to dynamically plug or un-plug network nodes during the operation of the networked system. Similar capability is desired in industrial automation, which extends it to a new level – the ability to handle information not only on changing equipment and its state, but on changing orders to be able to react to potentially new orders introduced to the automated production system at run time.

A set of standards were proposed by the industrial and the research communities to represent information on industrial automation systems. Among those, ISA-95-the No.95 standard for the Instrumentation, Systems, and Automation Society-addresses many aspects of the automation systems from manufacturing operations management point of view. The standard includes models for equipment, material, personnel, process segment, and others. Thus, to allow reconfigurability of industrial automation systems the ISA-95 has been selected for the implementation of information models.

This thesis work provides a solution for the industrial application of ISA-95. The thesis also defines an approach for the application of ISA-95 to industrial system, as there is a lack of a generalized approach and supportive applications for the standard implementation in industrial systems. A software tool (ISA-95 Tool) is implemented to facilitate the application of the standard. The Industrial System Development Life Cycle is revised to show the applicability of the standard for modelling industrial enterprise entities. B2MML is used as XML-based format representation for ISA-95. The developments are illustrated using two automated production lines.

Preface

This thesis work was carried out in Institute of Production Engineering at Tampere University of Technology, as a meaningful summary of my Master of Science Programme study of 2 years in Finland.

Here I would like to thank my parents for warming me up by their kind hearts till I have courage and confidence to make my own decisions.

I also wish to extend my thanks to my supervisor Andrei Lobov and Professor Jose L. Martinez Lastra for providing me strong and priceless support for the ideas and designs.

Xiaoyun Deng, Bo Zhou and all the other FAST members, your hard working encourages me a lot. Those hundreds of nights we spend together in the lab will always push me to move forward.

Tampere, April, 2012

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TERMS AND ABBREVIATIONS

ANSI	American National Standards Institute
B2MML	Business to Manufacturing Mark-up Language
BPEL	Business Process Execution Language
CORBA	Common Object Request Broker Architecture
DPWS	Devices Profile for Web Services
ERD	Entity Relationship Diagrams
ERP	Enterprise Resource Planning
GAO	U.S. Government Accountability Office
GUI	Graphical User Interface
HMI	Human machine Interface
ISA	the Instrumentation System, and Automation Society
JMEDS	Java Multi Edition DPWS Stack
MES	Manufacturing Execution System
ODE	Orchestration Direct Engine
OMT	Object Modelling Technique
OOAD	Object-Oriented Analysis & Design
OOSE	Object-oriented Software Engineering
OPC	OLE for Process Control
OASIS	Organization for the Advancement of Structured Information Standards
PFC	Procedure Function Chart
SCADA	Supervisory Control and Data Acquisition
SDLC	System Development Life Cycle
SIIS	Software Intensive Industrial System
SOA	Service-Oriented Architecture
SOAP	Simple Object Access Protocol

SSD	System Sequence Diagram
SQL	Structured Query Language
UML	Unified Modelling Language
UDDI	Universal Description, Discovery and Integration
UP	Unified-Process
WS4D	Web Service for Devices
WSDL	Web Service Definition Language
XML	Extensible Mark-up Language
XSD	XML Schema Language

1. Introduction

1.1 Motivation and Problem Definition

The information flow in industrial system is getting larger both on its size and complexity. The developing tendency of industrial systems shifts towards SIIS (Software Intensive Industrial System) where software contributes essentially to the design, construction, deployment and evolution in these systems. Being told the difficulty of creating such systems is not news. GAO, known as U.S. Government Accountability Office, attributes the poor success degree [1] of building software intensive systems to the management [2], in detail, ERP and MES levels.

From modules to methodologies, from languages to services, several sets of ways have been tried ,within 20 years, on connecting enterprise, control system and on refining the SDLC (system development life cycle).

The examples are not limited to the following list: SOA (Service-Oriented Architecture) – a paradigm developed for organizing and utilizing distributed capabilities under different ownership domains [3]; OPC (OLE for Process Control) – a common bridge for windows-based software applications and process control hardware; loose coupling – a mechanism keeping different part in one system maintained their own functionalities with communicating with each other through well-defined interfaces [4],etc.

But the trials only focus on part of the solution, or cover much wider than the specified field. For solving this problem, ISA-95 defines a complete functional model for enterprise-control use as reflection of an organizational structure of functions which can be replaced reaching different demands.

ISA-95 is originally a U.S. standard developed by the Instrumentation, Systems and Automation Society, which has been adopted as an international one under IEC (International Electro technical Commission)/ISO (International Organization for Standardization) 62246. As currently envisioned, the ANSI (American National Standards Institute) /ISA-95 series will consist of 5 parts, Enterprise-Control System Integration.

- Part1:Models and terminology
- Part2:Object model attributes
- Part3:Activity models of manufacturing operation management
- Part4:Object models and attributes of manufacturing operations management
- Part5:Business to Manufacturing transactions

The latest versions of Part 1, 2 and 3 are released on 2010 while part 4 and part 5 are still under standardization. In this thesis work, a version released in 2000 of Part 1, a version released in 2001 of Part 2 and a version released in 2005 of Part 3 are selected to make a stable company with B2MML (Business to Manufacturing Mark-up Language) (version 4010) for their compatibilities.

ISA-95 includes 3 main information areas of products, capabilities, and production as a 5-level-structrued standard. Besides, the standard provides a reference model for system organizing, allocating business to the different systems and information flow between systems [5].

The tools to be introduced in this thesis work—“ISA-95 Tool” and “FASTory GUI (Graphical User Interface)” serve as system boundary dealing with all the classes beyond and under problem domain defined in ISA-95.00.02. In majority of the industrial systems, the problem domain consists of 4 models [6]:

1) The personnel object model describes human resources defining different classes of personnel.
2) The equipment object model is structured similarly--the object model supports specifying requirements for different equipment classes.
3) The material model describes raw materials, intermediate products, and finished products.
4) A process segment is one step/task/unit of work that must be performed to complete a product.

The 5 other object models defined in ISA-95.00.02 beyond problem domain are production capability model, process segment capability model, product definition information model, production schedule model, production performance model. They compose the upper level beyond problem domain.

For its high flexibility and continuity, ISA-95 is internationally used and has 30,000 members all over the world.

With a set of XML (Extensible Mark-up Language) meeting W3C (World Wide Web Consortium)'s XML Schema language, as known as XSD, B2MML is treated as a complete XML implementation of ISA-95. The .xsd templates implement the data models in the ISA-95 standard. In the case of ISA95-Tool, .xml files are created as final information carrier following B2MML templates [7].

From the perspective of an SDLC, the “support phases” [8] in ISA-95 are still weak. This is reflected in the lack of tools and platforms based on the standard. This stage of conceptualization greatly demands specific visualization to increase engineers’ efficiency on familiarizing and using this standard. The thesis work aims to improve the manufacturing production efficiency by optimization of the information exchange between ERP and MES level. This is aided by a tool developed in accordance with the models in ISA-95, which also should contribute to the supporting phase of one industrial system.

One of the case studies is a production line by FESTO located at FAST (Factory Automation and System Technology) Lab, Tampere University of Technology. “ISA-95 Tool” is used to demonstrate the application of ISA-95 for the case study.

Another study case in this thesis work is FASTory Line that is an assembly line used for research purposes in FAST Lab.

A modified version of “ISA-95 Tool”—“FASTory GUI” is also developed as an alternative scenario built for target system. The detailed functionalities and related researches are also presented.

1.2 Thesis Outline

As an introduction, the first chapter of the thesis work introduces the main content and structure of the paper.

The second chapter contains a review of the previous work done in the very field and cites related methodologies and theoretical model. Different from other works, this thesis gives a comparatively comprehensive introduction of the methodologies in the right beginning of the work, which increases the complexity of the content but keep the integrity of the big structure.

This part starts from introducing one mechanism functioning in basic level, tracking the reason of its being used in the architecture, in the standard and in the system. A bottom-up state method is used for a better understanding of the inter connection.

Chapter 3 discusses in detail the approaches and models built before the implementation work on this thesis work. 3 different types of UML (Unified Modelling Language) models are used presenting the information structure building for FASTory Line and FESTO Line; the toolkit functions as system boundary in sequence models and use case models. Fully developed description and intermediate description table is created as a manual to the models.

Chapter 4 is for the implementation and application of the thesis work, including the building and the use of the tools—“ISA-95 Tool” and “FASTory GUI”. Different phases in the software are presented by screenshots and the intermediate prototyping flow is displayed. Besides, a necessary introduction to B2MML and its interfaces to ISA-95 are also explained.

Chapter 5 analyses the structure and the information inside one created example .xml file, known as the work result. The results from the 2 toolkits are compared and the benefits and drawbacks are listed separately. Also part of the BPEL file is also listed as part of the implementation work.

Chapter 6 is a conclusion to the whole topic and list possible after work in the future research, followed by reference and appendices in the end.

2. The State of the Art

2.1 Mechanisms, Architectures and Standards

From loose coupling mechanism to standards such as OPC and ISA, engineers aim on the common target to reduce the need for human work in the production of goods and services, which is tried to be reached by different efforts on getting industrial models dynamically involved.

2.1.1 Loose Coupling mechanism

From the perspective of structural analysis, the connections of industrial entities are paid enough attention several decades ago. However, the efforts did not go further to its goal—also the goal of every information evolution—the connection between information systems. The tendency of connecting entities with well-defined interfaces without breaking flexibilities, together with the development of information systems itself makes ISA-95 a suited solution, or a so-called interface for this task.

Loose coupling means that different part of one system will maintain their own functionalities and will communicate through a well-defined interface [4].

In the report of “Toward the definition of the Loose Coupling notion in a Composite Service” by Anthony Hock-koon and Mourad Oussalah, loose coupling is defined in more detail from prospective of semantic, syntactic and physical level.

Semantically, loose coupling means an abstract service and a composite loosely coupled if this service participates in a non-essential capability of this composite and these capabilities have a direct impact on the composite efficiency.

Syntactically, loose coupling stands for an abstract service loosely coupled with a concrete service if there are optional solutions. The more there are suitable concrete services, the weaker the coupling is.

Physically, a service can be seen loosely coupled if it is linked with more than one other service (theoretically its composite service).

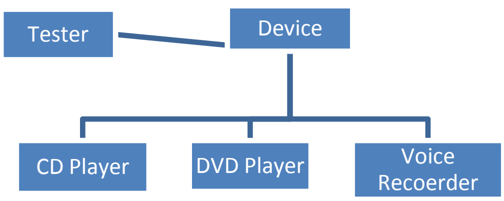

Figure 2.1*An Example of Loose Coupling Mechanism*

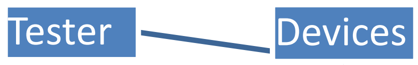

Figure 2.2 *an example of Strong Coupling Mechanism in comparison*

The need for loose coupling mechanism comes from the requirement of business processes and business applications flexibility. The processes and applications need to make constant modifications to cater the new environment due to the changes in policy, partnership and business focal point. In so-called on demand business, this mechanism reacts to the changes in short time and reduces the cost for the modification.

As architecture with well-embedded loose coupling mechanism, SOA is worth mentioning example with its high flexibility, reusability and stability.

2.1.2 SOA

There is always a need for intelligent SOA approaches in manufacturing operations management. And one of the issues that the ISA-95 standard addresses is the interface or exchange of data between the extended enterprise systems (sales, planning, scheduling, and procurement).

The definition of SOA from OASIS (Organization for the Advancement of Structured Information Standards) is:

"A paradigm for organizing and utilizing distributed capabilities that may be under the control of different ownership domains. It provides a uniform means to offer, discover, interact with and use capabilities to produce desired effects consistent with measurable preconditions and expectations." [3]

It is widely used in web service [9], pervasive computing [10] and business applications in general.

Typically, those environments are envisioned to embody a number of devices with a very rich set of functionalities. As many as possible resources are integrated in the environment in an efficient way to provide the best support for user tasks and to embody varying functions in a set of devices. The environments equip the ability to extract these needs and build their replies according to their own capabilities. [11]

SOA in early times describes how services consumers and services providers can be decoupled via discovery mechanisms in loosely coupled systems. Implementing a service-oriented architecture means at the same time to deal with heterogeneity and interoperability concerns. [12]

However, SOA in nowadays becomes the alternative model of object-oriented model which has been existing for 20 years (object-oriented models are strongly coupled). Although SOA does not exclude methodologies of object-oriented design (in building single services), its whole design methodology still focus on services. In some part of the SOA system, designers can be compatible with OOAD (Object-Oriented

Analysis & Design without going against the core of its methodology. Chapter 2.1.3 in this thesis is about the application of UML following OOAD's track with the Unified Process (as UP hereafter).

In recent years, SOA extends its development based on XML. It uses Web Services Definition Language, as known as WSDL, to describe interface stepping to an adaptable and robust mode beyond Interface Definition Language in CORBA (Common Object Request Broker Architecture).

2.1.3 UML

UML, known as Unified Modelling language, is a specification defining a graphical language for visualizing, specifying, constructing, and documenting the artefacts of distributed object systems [13]. The object models in ISA-95 are depicted using the Unified Modelling Language8 (UML) notational methodology.

The Object-oriented modelling language ushers a harvest season in the year between 1989 and 1994. During this time, the amount of Object-Oriented language creeps from less than 20 to more than 50.

It takes long time for model users to compare and choose a proper language for their models; moreover, the language designers propagate and consummate their product in users' practical use to win the market. That period of time, is called "Method War" in history of computer science. The war comes to a dead-end until the middle of 90s a new languages broke this dilemma. It is developed by 3 designers who quit from the "battlefield", Grady Booch, James Rumbaugh and Ivar Jacobson.

As one of the advocates leading in Object-Oriented method, Grady Booch expands his work from Ada programming language to the wide domain of OO method. His work "Booch 1993" copes well with design of the system.

Meanwhile, the team of James Rumbaugh team raises the concept of "Object Modelling Technology". The purposes of this modelling are

- Testing physical entities before building them (simulation),
- Communication with customers,
- Visualization (alternative presentation of information), and
- Reduction of complexity. [14]

The 2nd version of OMT (Object Modelling Technique) copes well with analysis and description to data-based system.

Ivar Jacobson raises use case method in Object-oriented Software Engineering (as OOSE hereafter). Use-case method is a sharp weapon for describing system requirement and this method is kept in UML later. OOSE copes well with business engineering and requirement analysis.

The 3 designers each add properties from their original work to this new language, making the name standing out of the corps—Unified Modelling Language.

The software industry accepted this new bier in a short time and considered it as the standard modelling language for specifying software and system architectures. [15]

As a modelling notation, the influence of the OMT notation dominates (e. g., using rectangles for classes and objects). Though the Booch "cloud" notation was dropped, the Booch capability to specify lower-level design detail was embraced. The use case notation from objectory and the component notation from Booch were integrated with the rest of the notation, but the semantic integration was relatively weak in UML 1.1, and was not really fixed until the UML 2.0 major revision.

Concepts from many other OO methods were also loosely integrated with UML with the intent that UML would support all OO methods. Many others also contributed, with their approaches flavouring the many models of the day, including: Tony Wasserman and Peter Pircher with the "Object-Oriented Structured Design (OOSD)" notation (not a method), Ray Buhr's "Systems Design with Ada", Archie Bowen's timing analysis, Paul Ward's data analysis and David Harel's "Statecharts"; as the group tried to ensure broad coverage in the real-time systems domain. As a result, UML is useful in a variety of engineering problems, from single process, single user applications to concurrent, distributed systems, making UML rich but also large [16].

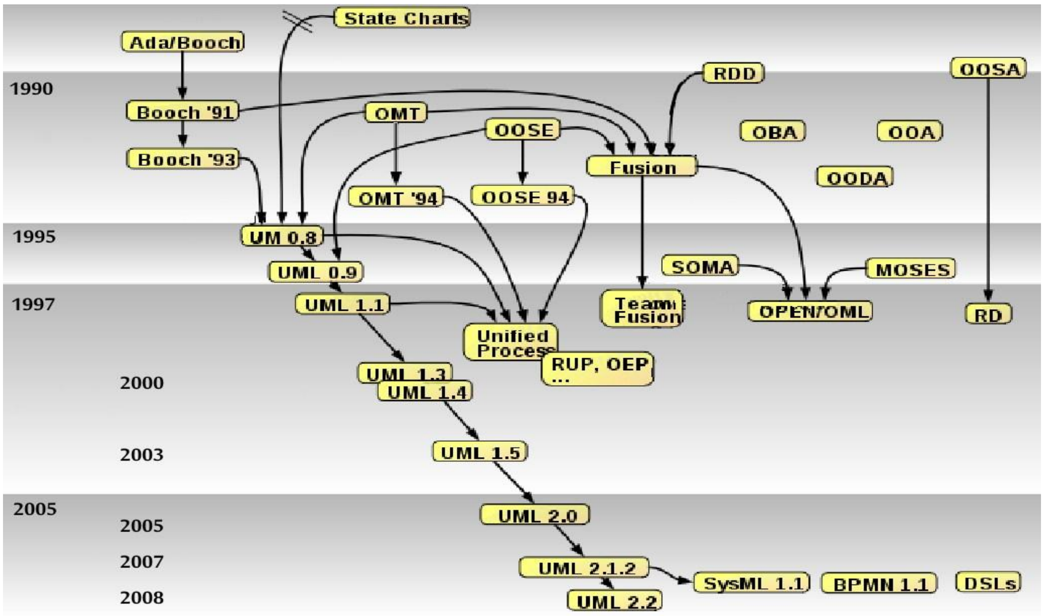

Figure 2.3 *History of object-oriented methods and notation [17]*

Although UML is primarily intended for general-purpose modelling, it's expended to diverse specialized areas in UML Fig. 2.3. [17]

Beginning with UML 2.0, the UML Specification was split into two complementary subsets: Infrastructure and Superstructure. The UML infrastructure specification defines the foundational language constructs required for UML 2.0. It is complemented by UML Superstructure, which defines the user level constructs required for UML 2.0. The two complementary subsets constitute a complete specification for the UML 2 modelling language. [18] [19]

UML has matured significantly since UML 1.1. Several minor revisions (UML 1.3, 1.4, and 1.5) fixed shortcomings and bugs with the first version of UML, followed by the UML 2.0 major revision that was adopted by the OMG in 2005. [20]

Although UML 2.1 was never released as a formal specification, versions 2.1.1 and 2.1.2 appeared in 2007, followed by UML 2.2 in February 2009. UML 2.3 was formally released in May 2010. [21] UML 2.4 is in the beta stage as of March 2011.

In the book of "Object-oriented Analysis & Design with the Unified Process" by John W.Satzinger, Robert B.Jackson and Stephen D.Burd, a model-driven approach to analysis starts with use cases and scenarios and then defines problem domain classes involved in the users' work. Requirements discipline with use case diagrams, use case descriptions, activity diagrams, and system sequence diagrams.

In this thesis work, the information mentioned above are expressed in a format of B2MML—an XML implementation of ISA family standards.

One deficiency is, the UML version they use is 2.0, in this version UML does not have XSD or XML files due to structural problems with the UML met model. [21]

The object models built with UML are also presented in Chapter 3 of this thesis work. UML (Unified Modelling Language) models are used in the development of the tools. The 9 object models, 86 objects and a whole set of attributes defined in ISA-95.00.02 are extensions to the information models defined in ISA-95.00.01.

The structure and the frame allow users of addressing own information inheriting the relationship between information blocks (known as classes in Object Models).

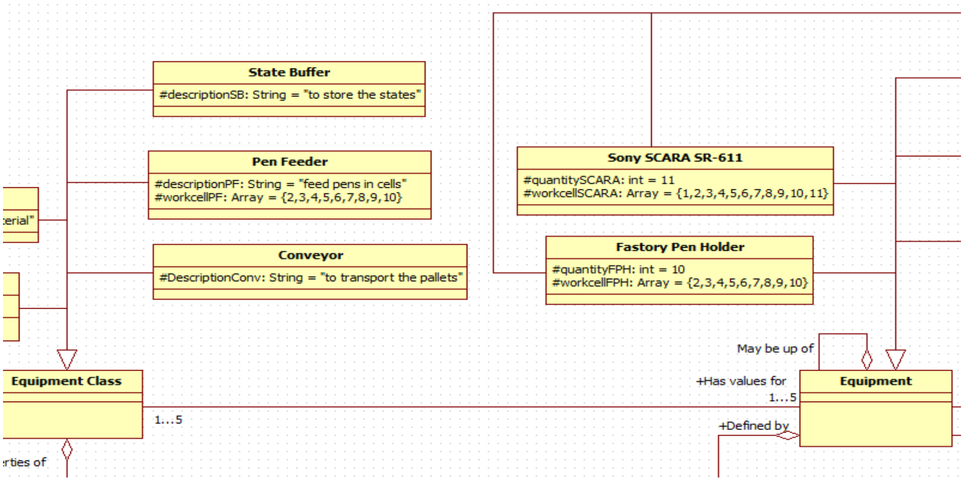

Figure 2.4 *part of Equipment Object Model for FASTory Line*

In an example of Equipment Object Model for FASTory Line, the information of "State Buffer", "Pen Feeder", "Conveyor" is well classified and the generalization between "Equipment Class" and them is also kept.

2.1.4 OPC

It has become a common goal of all industrial standards, to allow simple and accurate through well-defined interfaces without stepping into programming interface and communication models in low level. OPC is one of the standards who inherits this characteristic and emphasises system's interoperability.

OPC is short for "OLE for process control" in industrial automation and the enterprise systems that support industry. Interoperability is assured through the creation and maintenance of open standards specifications. [22]

It has emerged as the worldwide industrial standard based on DCOM (Microsoft's Distributed Component Object Model) in recent years. The standard provides the interoperability of Office products and information system on the company level, including the core research domains of this thesis—ERP and MES. [23]

As a big part under development in OPC Foundation, OPC UA (Unified Architecture) "provides the automation industry a tremendous opportunity to gain efficiencies and create new solutions with the seamless interoperability of systems" [24].

Considering that the automation industry must have a sense on how technologies and innovations available today and tomorrow can provide a secure reliable interoperable solution that addresses real needs, the OPC Foundation has been focusing on collaborating with many of the other industry-standard organizations. The intention of the OPC UA is that the various other industry-standard organizations information models would be able to use this service to provide a complete solution for deterministic interoperability.

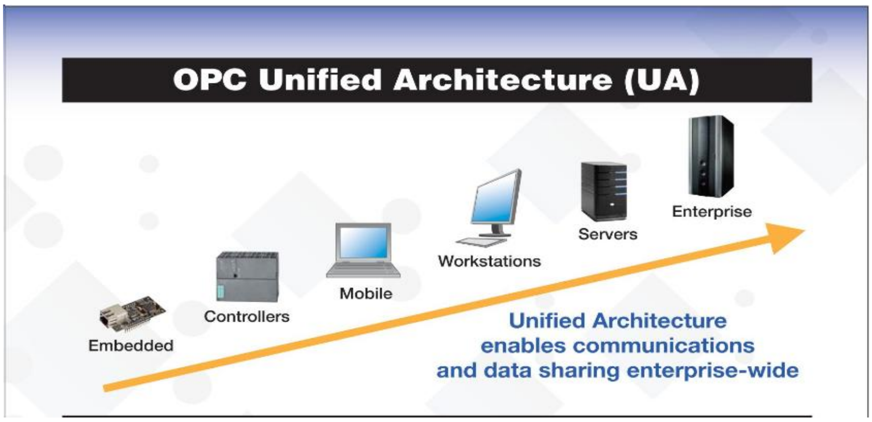

Figure 2.5 *OPC Unified Architecture* [25]

OPC was designed to provide a common bridge for Windows based software applications and process control hardware. Standards define consistent methods of accessing field data from plant floor devices. This method remains the same regardless of the type and source of data. An OPC Server for one hardware device provides the same methods for an OPC Client to access its data as any and every other OPC Server for that same and any other hardware device. The aim was to reduce the amount of duplicated effort required from hardware manufacturers and their software partners, and from the SCADA (Supervisory Control and Data Acquisition) and other HMI (Human machine Interface) producers in order to interface the two. Once a hardware manufacturer had developed their OPC Server for the new hardware device their work was done to allow any 'top end' to access their device, and once the SCADA producer had developed their OPC Client their work was done to allow access to any hardware, existing or yet to be created, with an OPC compliant server.

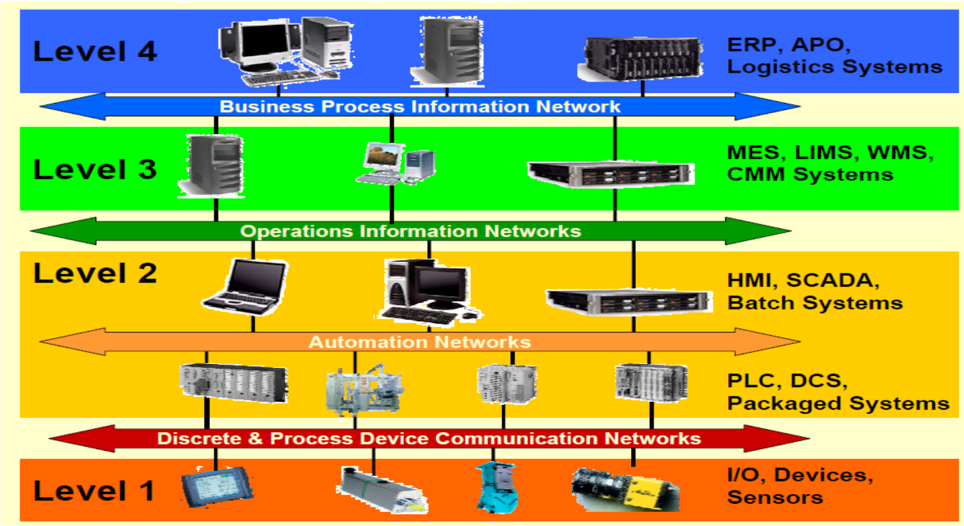

Figure 2.6 *Conceptual Topology from an IT View* [26]

2.2 ANSI/ISA standards

This chapter aims to give general description of 2 ISA standards—ISA-95 and ISA-88.

In an industrial entity, a master plan is needed to provide overall guidance for the development and implementation programs for the application of enterprise integration. Such master plan provides the company the necessary preliminary planning and operational guidance to be able to take full advantage of the above hardware and software developments. In this thesis work, “Handbook on Master Planning and Implementation for Enterprise Integration Programs” from Purdue Laboratory for Applied Industrial Control is referenced covering all of the anticipated effort required to integrate the whole of the involved operation. the work flow of the master plan is depicted in *Figure 2.7*. The figure charts the information flow in the master plan when suggested subject matters are used. The flow numbers in *Figure 2.7* are also the chapter number of the handbook. Eg. the content of “Chapter 1. Define Enterprise & Establish Initial Program” in the handbook deals with the first part in the work flow of “Define Enterprise Business Entity”.

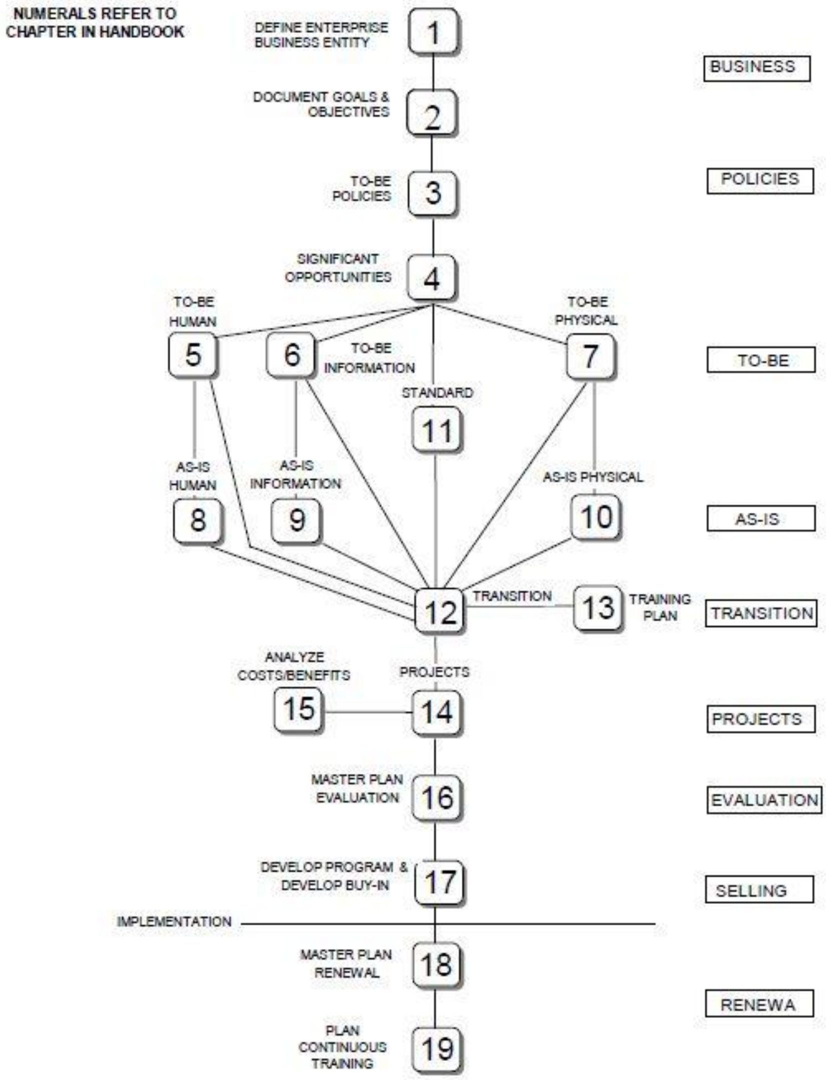

Figure 2.7 *PERA Master Planning Work Flow* [27]

The ISA-95 standard is developed with the objective to reduce the cost, risk and errors associated with implementing interfaces between enterprise and production control systems. All these characteristics make it a good standard for the "standard" step in a master plan.

2.2.1 ISA-95

ISA-95 defines a complete functional model for enterprise-control use (*Figure 2.8**Figure 2.8** Functional enterprise-control model*). The model structure does not reflect an organizational structure within a company, but an organizational structure of functions. Different companies will place the functions in different organizational groups.

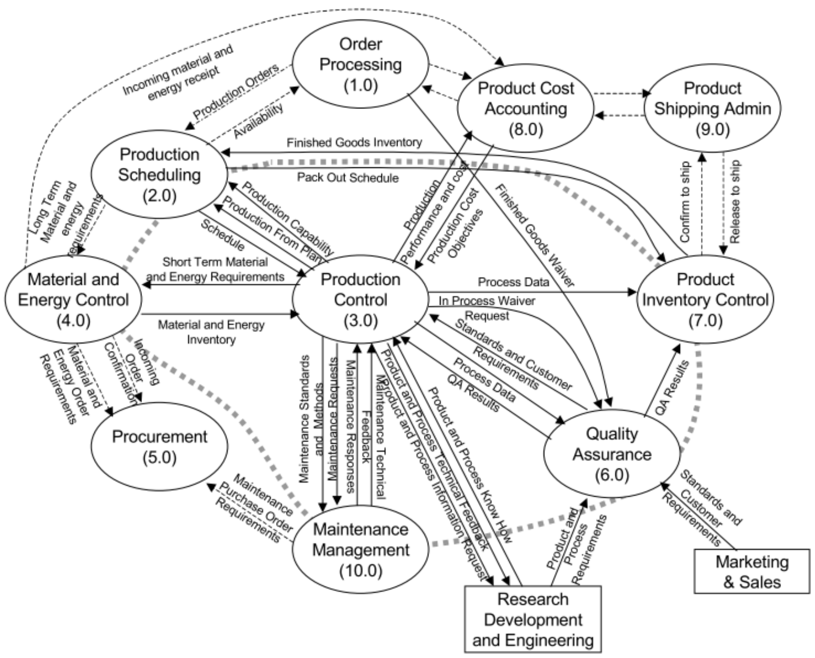

Figure 2.8 *Functional enterprise-control model* [28]

Most of the information described in this functional model falls into three main areas:

a) Information required producing a product
b) Information about the capability to produce a product
c) Information about actual production of the product

The Software Intensive Industrial System mentioned in Chapter 2, is set as example of one production line in FAST Lab in Tampere University of Technology—FASTory Line.

ISA-95 is the international standard being developed for integrating enterprise and control systems. It provides a reference model for system organizing, allocating business to the different systems and information flow between systems. ISA-95 is originally a U.S. standard, but it has been adopted as an international standard under IEC/ISO 62246. [5]

The purpose of the standard [27] is to:

a) Emphasize good integration practices of control systems with enterprise systems during the entire life cycle of the systems;
b) Can be used to improve existing integration capabilities of manufacturing control systems with enterprise systems
c) Can be applied regardless of the degree of automation

In accordance to other standards format in the same series (E.g., ISA 88, ISA 100.11a in ISA family), ISA-95 has 5 international parts:

- ISA 95.00.01 Models and Terminology (Also IEC/ISO 62264-1)
- ISA 95.00.02 Object Models and Attributes„ (Also IEC/ISO 62264-2)
- ISA 95.00.03 Activity Models of Manufacturing (Operations Management)

- ISA 95.00.04 Object Models and Attributes of Manufacturing Operations Management
- ISA 95.00.05 Business to Manufacturing Transactions

ISA-95 defines a functional hierarchy, illustrated in a Functional hierarchy model

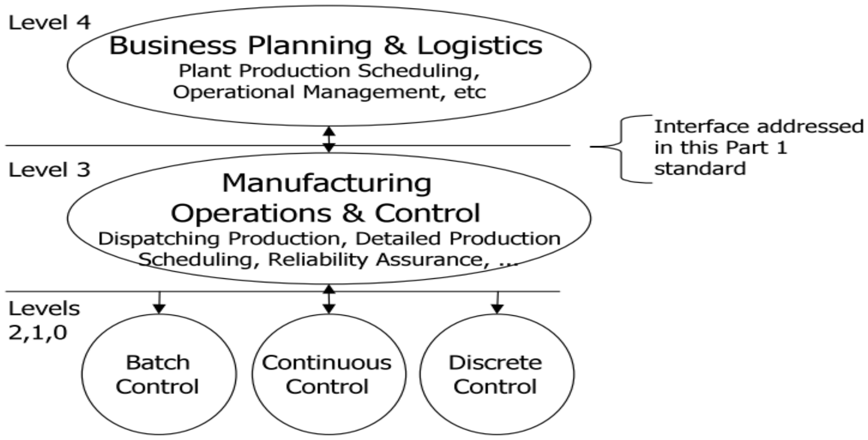

Figure 2.9 *Multi-level functional hierarchy of activities* [28]

Each level provides specialized functions and has characteristic response times, as shown in *Figure 2.9**Figure 2.9** Multi-level functional hierarchy of activities* [28].

a) Level 0 defines the actual physical processes.

b) Level 1 defines the activities involved in sensing and manipulating the physical processes. Level 1 typically operates on time frames of seconds and faster.

c) Level 2 defines the activities of monitoring and controlling the physical processes. Level 2 typically operates on time frames of hours, minutes, seconds, and sub seconds.

d) Level 3 defines the activities of work flow to produce the desired end products. It includes the activities of maintaining records and coordinating the processes. Level 3 typically operates on time frames of days, shifts, hours, minutes, and seconds.

e) Level 4 defines the business-related activities needed to manage a manufacturing organization.

The standard presents the functions of an enterprise involved with manufacturing, notational methodology which describes information flows between interfaces [29], the categories of information [27] and the definition of the attributes [30] in object models.

As discussed in [8], "a model is a representation of some aspect of the system being built. A variety of models should be built to encompass the detailed information that an analyst collects and digests". ISA standards make full use of activity models in manufacturing operations management. Being cited in a generic activity model in *Figure 2.10**Figure 2.10** Generic activity model of manufacturing operations management [28]*, there extends 4 sub models (production operations, maintenance operations, quality test operations and inventory operations) and the connection between each module block is described specifically.

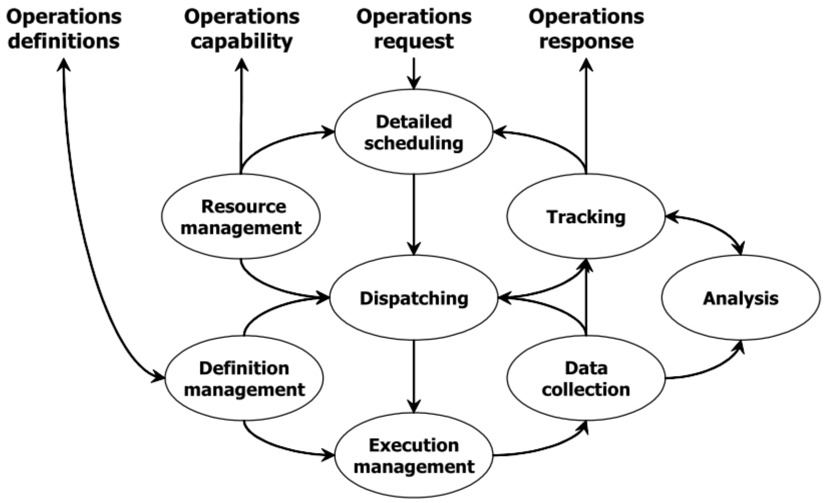

Figure 2.10 *Generic activity model of manufacturing operations management [28]*

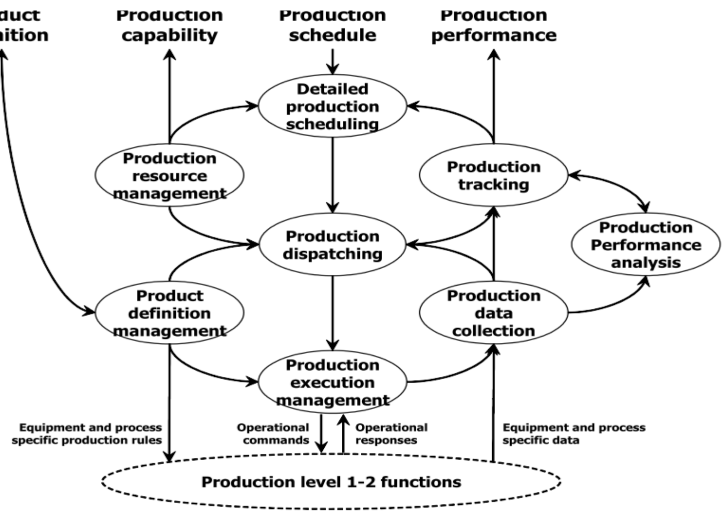

Figure 2.11 *Activity model of production operations management--an example* [28]
extension model of activity model in manufacturing operation [28]

As mentioned, the objectives of ISA-95 are to provide consistent terminology that is a foundation for supplier and manufacturer communications. What is important to SIIS is that ISA-95 provides consistent information models and operations models for clarifying application functionality and how information is to be used.

2.2.2 ISA-88

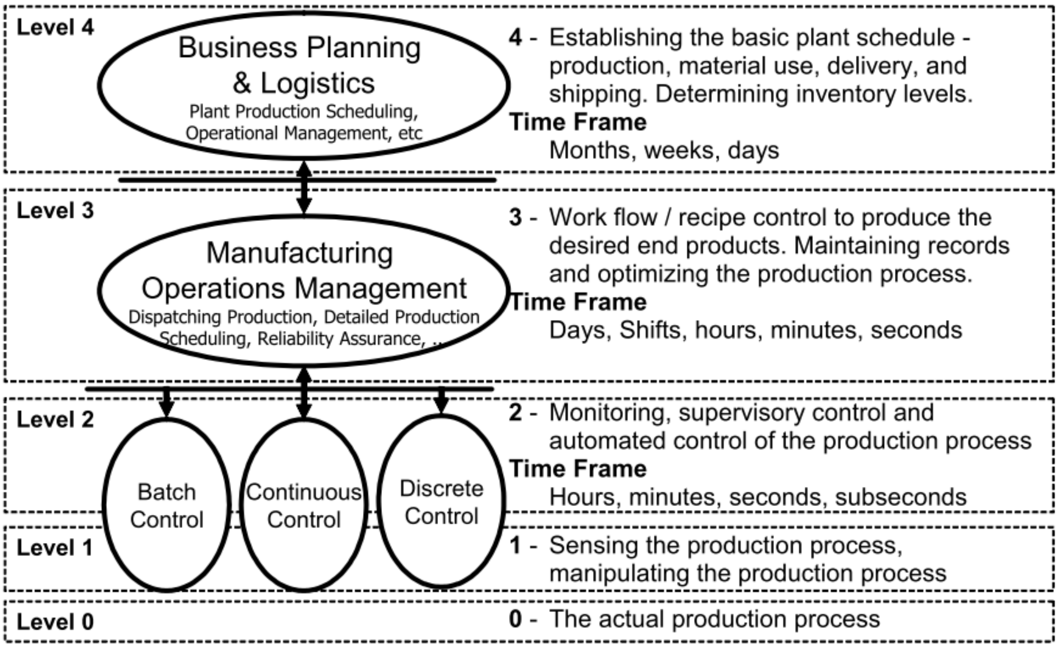

Figure 2.12 *a detailed version of Multi-Level Functional Hierarchy of Activities* [31]

As in *Figure 2.12*, ***Figure 2.12*** *a detailed version of Multi-Level Functional Hierarchy of Activities* of multi-level functional hierarchy of activities, "Batch Control" contributes to the interface between Level 2 and Level 1. ISA-88 is the very standard focusing on informative and normative information on Batch Control.

2.2.2.1 Batch control

Industrial manufacturing processes can be classified as either process manufacturing or discrete parts manufacturing. Process manufacturing can be further classified as continuous, batch or combination of the two.

Continuous process manufacturing automatically react to parameters' change without making modifications to the system while in discrete parts manufacturing any changes must be made after cutting the production procedure.

Batch processes are discontinuous processes, which are neither discrete nor continuous but have characteristics of both. *Figure 2.13****Figure 2.13*** *Standards in the batch control series [31]* is a structure of ISA 88 series' functionality.

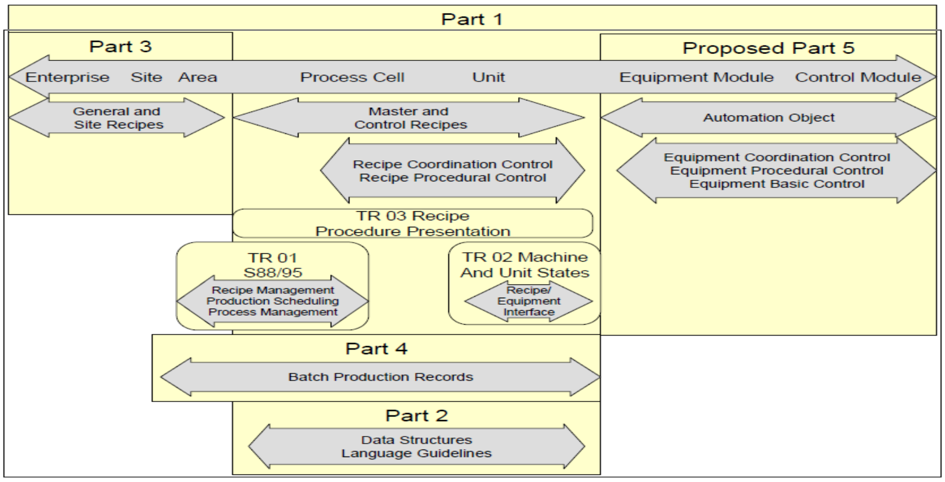

Figure 2.13 *Standards in the batch control series [31]*

Part 5 of ISA 88 is not yet released as a formal documentation. A comprehensive jointing system of SP88 and SP95 is presented in Technique Report 01.

2.2.2.2 Models in ISA 88

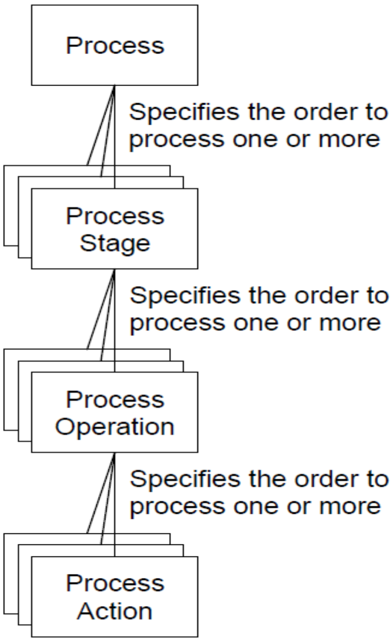

Figure 2.14 *Process model (instance diagram) when not collapsed or expanded*

Take the process model as an example, any process can be generally divided into 4 process stages. ISA 88 defines the content of every stage [31, Clause 4.3.3 … Clause 4.3.5] and introduces the collapsing and expansion of the structure [36, Clause 4.3.6].

And the process stages in this model correspond to the other four stages in Procedural Control Model individually. In *Figure 2.15*, it indicates that the corresponding relationship of Process Model, Procedural Control Model and Physical Model in factory floor shop.

Ref [31, Clause 5] divide structure for batch control into 3 categories: basic control, procedure control & coordination control. Coordination Control has the function of "directing, initiating and modifying" procedural control and [31, Clause 5.4.1] gives a series of examples. One should be mentioned that procedure is a particular structure only exists in batch control, its process-oriented characteristic further explain the feasibility of being built upon process models.

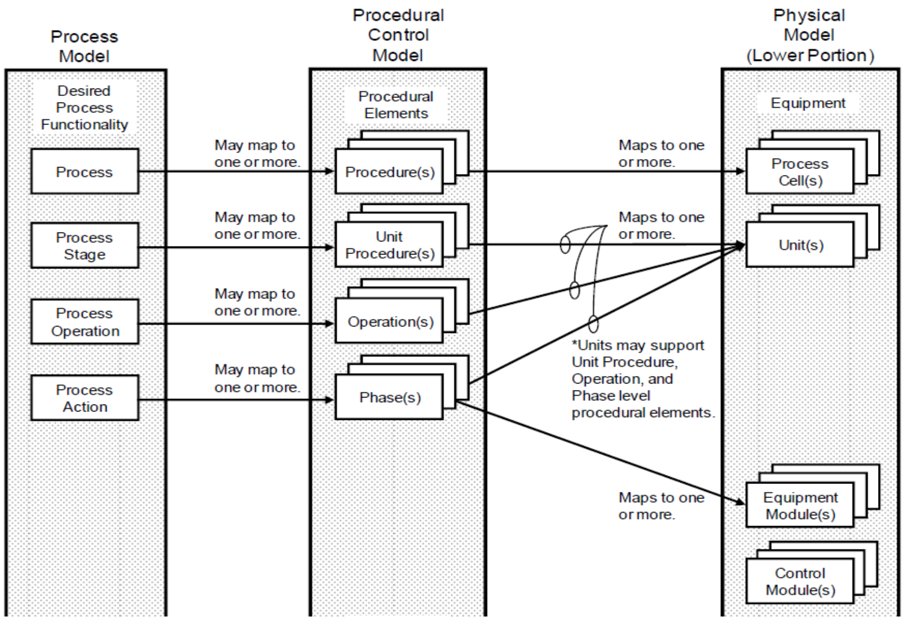

Figure 2.15 *Typical process/procedure/equipment mapping to achieve process functionality* [31]

A close look at Physical model again explains the different working field of SP88 and ISA95-62246—the enterprise, site, and area levels are more precisely defined in the IEC/ISO 62264 and ANSI/ISA-95 standards (in dash lines in *Figure 2.16*) while SP88 focuses on the parts in lines. Also, this structure is kept in further descriptions to equipment entities.

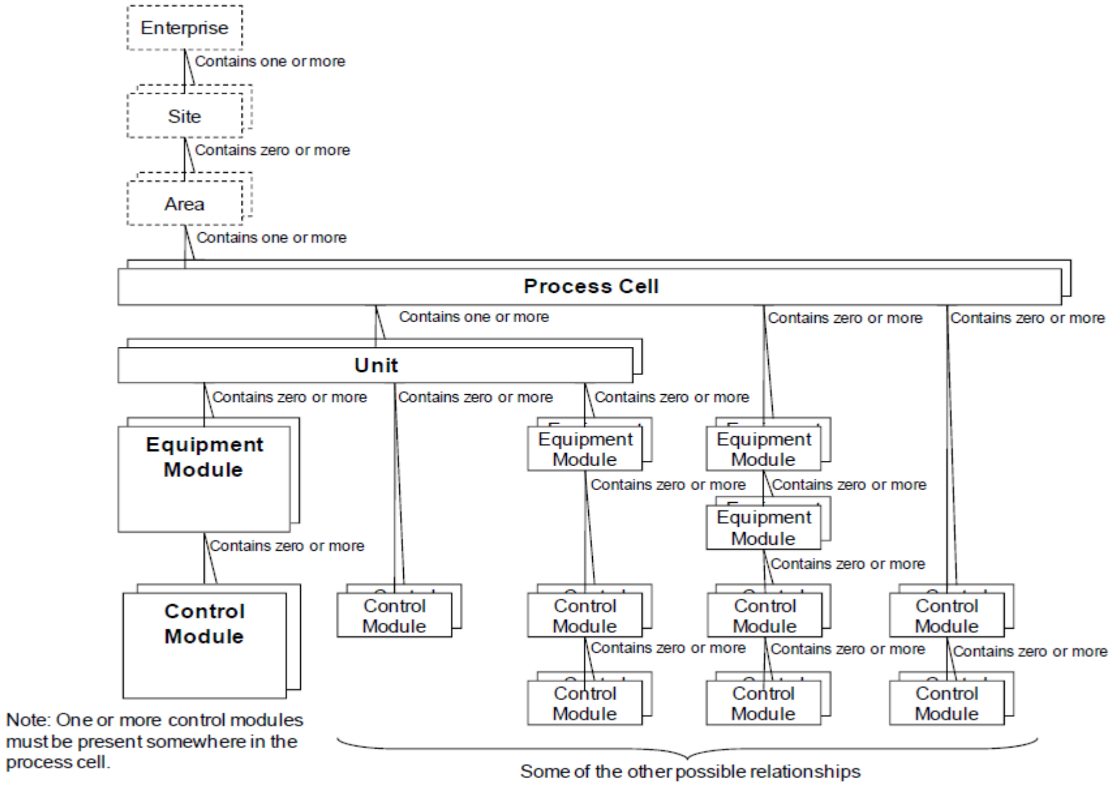

***Figure 2.16** Physical Model in Part 1, SP88* [31]

2.2.2.3 Recipe

A recipe a collection of information that uniquely defines the manufacturing requirements for a specific product, intermediate or equipment status change such as clean-in-place, sterilize, etc.

The essence of recipe is a collection of components [31, Clause 6.4]; *Figure 2.17* gives a landscape of the components.

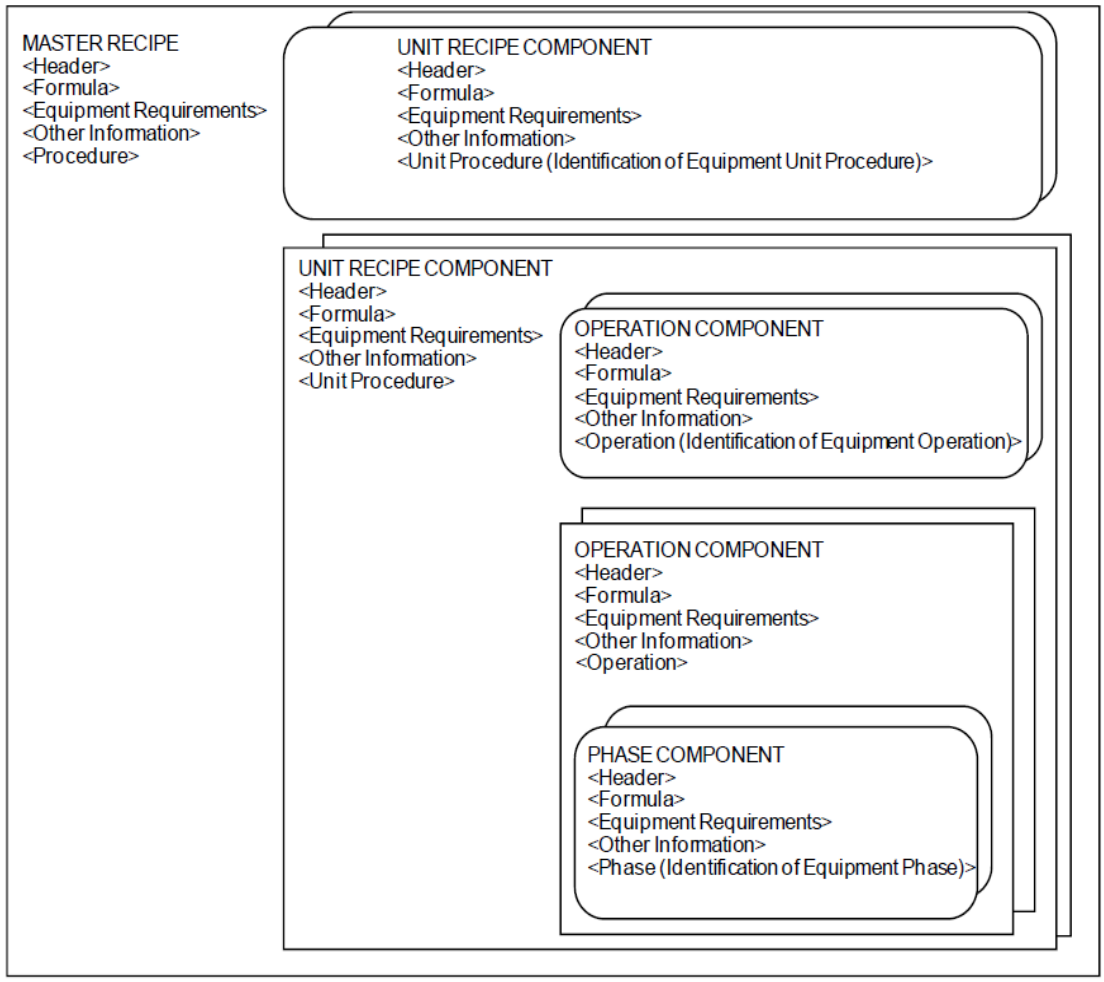

Figure 2.17 *an example of recipe component encapsulation* [31]

There defines 4 recipes in this standard—general recipe, site recipe, master recipe and control recipe, which are used in enterprise level, site area and equipment level, separately. General recipe and site recipe can be transformed to master recipe and control recipe and control recipe comes from the copy of master recipe. A recipe type model is built for this relationship.

The concept of recipes allows for a high degree of processing flexibility that is essential in many batch processes and allows for significant changes in process activities to be defined by a recipe author without re-engineering equipment entities.

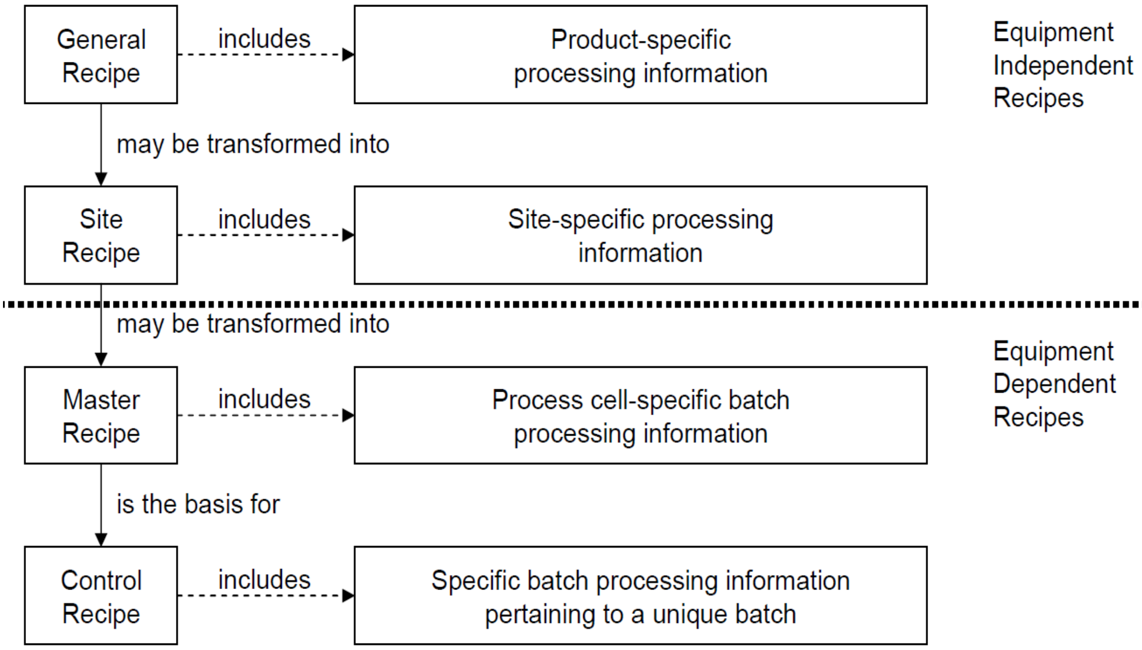

Figure 2.18 *Recipe types model* [31]

Besides, both general recipe and master recipe can be divided into 4 stages defined in procedural control model. [31, Clause 6.6] focuses on the interfaces between control recipes and equipment level by analysing the convergence of procedures.

Other 8 factors as process segmentation, exception handling, modes and states in [31, Clause 7] are not considered in FASTory Line's case.

2.2.2.4 Object Models in SP88

SP88 Part 2 uses a series of modelling languages in different clauses [32]. Ref [32, Clause 4] defines data structure in a form of data models, the language is UML.

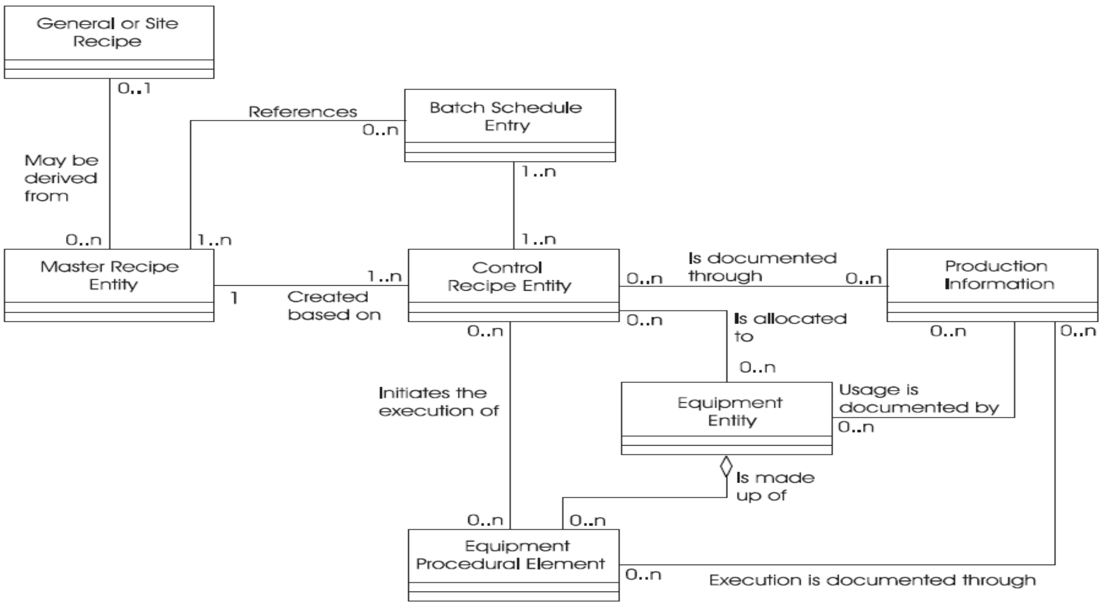

Figure 2.19 *Overview model of SP 88*[31]

In practical use, not every component is included in this overview model. E.g., [32, Clause 4.3.4] uses a table of 10 attributes and a separate object model (building block concept model for factory recipe system) to finish its description.

While [32, Clause 5] defines the structure of SQL (Structured Query Language) relational tables for the exchange of selected batch control related information between systems. Meeting with the requirements in Clause 4, the exchange of batch control information are in 4 categories: Master and control recipe information, Process cell equipment information, Schedule information and Production information.

The correlation of information exchange is visualized with ERD (Entity Relationship Diagrams) language and recipe depiction methodologies in Clause 6 are in PFC (Procedure Function Chart) language.

A large amount of tables and attributes enlarge the difficulty to apply ISA 88 in production lines; ISA 88 provides a definition list to instantiate the deployment. Another salvation for this is the large capability of the whole standard, an explanation to this facet can be found in [32, Clause 5.1.2]—the exchange table structure allows the transfer of either complete or incomplete subsets of a master recipe, equipment description, etc.

The study case in this thesis—FASTory Line is still under test and adjustment for research use, the capability makes it easier to integrate the incomplete information from the production line into the SP88 models.

2.2.2.5 Equipment-Independent recipe

Instead of introducing general and site recipes separately, SP88 Part 3 uses the super class of these 2 recipes—equipment-independent recipe [33]. An equipment-independent recipe can be used either “as input to trial or pilot plant production” or “as a result of trial or pilot plant production”. *Figure 2.20* is an example of the application in these two fields.

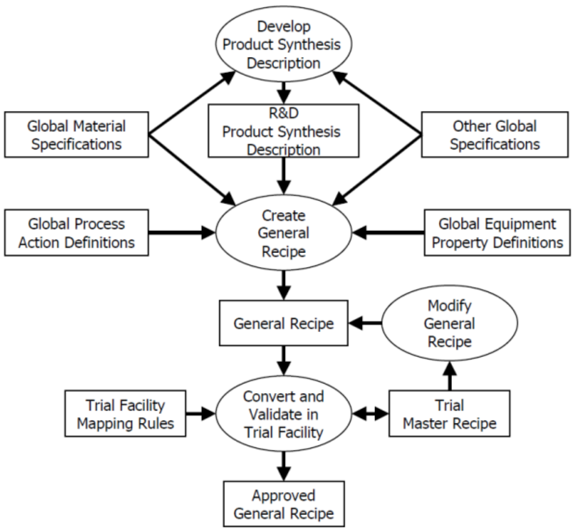

Figure 2.20 *Pilot plant creation of equipment-independent recipe* [33]

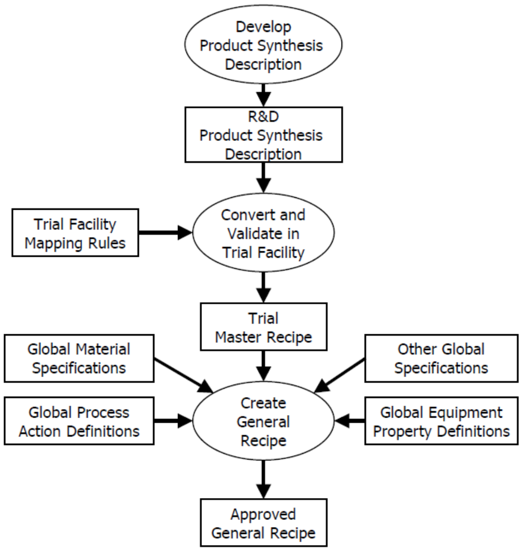

Figure 2.21 *Equipment-independent recipe from pilot plant development* [33]

Ref [33, Clause 6] also builds object model for equipment-independent recipe and give short description to classes in this model.

2.3 Web service for information exchanging

As mentioned in the introduction, the information exchanged between the production line and the low level controller will be packaged in .xml file. So the web service is also designed for bridging MES and ERP levels in FASTory Line.

The significance of web service is self-contained and self-describing application components. They communicate with open protocols. XML is the basis for every web service.

The basic platform of web service is XML plus HTTP. XML provides a language which can be used between different platforms and programming languages and still express complex messages and functions.

The web service technologies involved in this thesis work are introduced in the following part.

2.3.1 WSDL & BPEL

Following the description on WSDL in 2.1.2 in this thesis work, WSDL is an XML format for describing network services as a set of endpoints operating on messages containing either document-oriented or procedure-oriented information. The operations and messages are described abstractly, and then bound to a concrete network protocol and message format to define an endpoint. Related concrete endpoints are combined into abstract endpoints (services). WSDL is extensible to allow description of endpoints and their messages regardless of what message formats or network protocols are used to communicate.

Together with SOAP (Simple Object Access Protocol) and UDDI (Universal Description, Discovery and Integration), WSDL is one of the 3 platform elements of a typical web service. Each move in the production line can be traced to an operation in a .wsdl file.

BPEL (Business Process Execution Language), short for Web Services Business Process Execution Language (WS-BPEL) is an OASIS (Advancing Open Standards for the Information Society) standard executable language for specifying actions within business processes with web services. Processes in BPEL export and import information by using web service interfaces exclusively. Namely, BPEL orchestrates services that are exposed using WSDL and define business processes that interact with external entities through web services operations, which is also one of the design goals of BPEL. One example on FASTory Line to explain this is, as for one of the robot cells, a .wsdl file works well on triggering its operations as “selecting pens”, “calibrate” and “state change feedback”. But to visualize more complicated tasks between all the elements in each robot cell, the orchestration becomes necessarily in this step.

2.3.2 WS4D

WS4D is an abbreviation for Web Services for Devices and enables Web Services, the foundation of Web 2.0, on networked embedded systems (devices). Cell phones, wireless sensor nodes and a wild range of automation devices are some notable examples. The application can be developed regardless of the heterogeneous devices with different capabilities and communication standards. All the WS4D toolkits released officially implement the DPWS (Devices Profile for Web Services) [34].

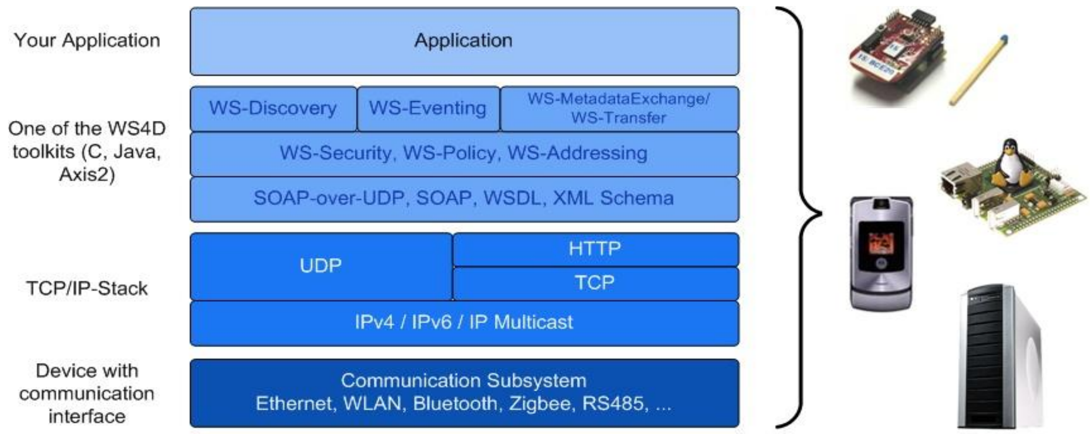

Figure 2.22 *WS4D in the structure of communication* [34]

2.3.3 JMEDS

JMEDS is the WS4D.org Java Multi Edition DPWS Stack [35]. It is a framework that allows implementing and running DPWS Services, Devices and Clients. JMEDS supports different Java Editions, including Java ME CLDC.

Part of the stack package is modified by laboratory members for better supporting the devices before practice use. Here lists the features of the JMEDS framework:

- *Versatility of the platform supports all java editions:* The JMEDS Local Toolkit feature supports all Java platforms from CLDC up to SE and allows the usage of platform specific features like disk and network access. With JMEDS it is possible to choose the best platform for purpose.
- *Scalability :*JMEDS is suitable for embedded devices with low amount of memory and restricted computing power as well as for computing systems without such limitations. The modularity of JMEDS allows the usage of different modules to fit the needs of your project and ensures high adaptability.
- *Resource effective:* With the module system it is possible to reduce the size of JMEDS to save resources on your device. JMEDS uses only a minimal set of external libraries to minimize the necessary dependencies. JMEDS is a lightweight frame work.
- *Generic web interface:* JMEDS comes along with a generic web interface which allows fast access and usage of your services with your favorite web browser.
- *Interpretation of WSDL at runtime:* It is not necessary to create a WSDL neither for your service nor for your device. The JMEDS generates the WSDL on the fly within the request.
- *Compatibility:* JMEDS is built for high compatibility, supports Microsoft Windows 7 and is tested with the University of Rostock DPWS Stack.

2.3.4 Server

Tomcat and Resin are both open source servers with strong functionalities. The extended versions have good support on business uses. While for medium and small size industries as FASTory Line, basic version can cover most of the applications.

2.4 Problem statement

From mechanisms to standards, engineers make variety of trials on optimization of automation systems in different levels and from different sights. Before ISA-95, there is still lack of targeted standards connecting enterprises and control systems. Besides, the supporting phase of system development life cycle of the standards is still weak. The tools developed for this purpose set ground for systematic application of ISA-95 facilitated, which lead to the optimization of the information exchange between ERP and MES level in an industrial system.

3. Approaches and Models

3.1 Refining of SDLC

For a system development project, the success depends heavily on plans with organized, methodical sequence of tasks and activities. One of the fundamental factors in information development is the system development life cycle (as SDLC hereafter).

As we know, there are varies of information systems supporting business processes. Each of them has a lifetime of its own. From the phase an idea is conceived, designed, built, deployed in a project and finally put into production, the process is SDLC. [8]

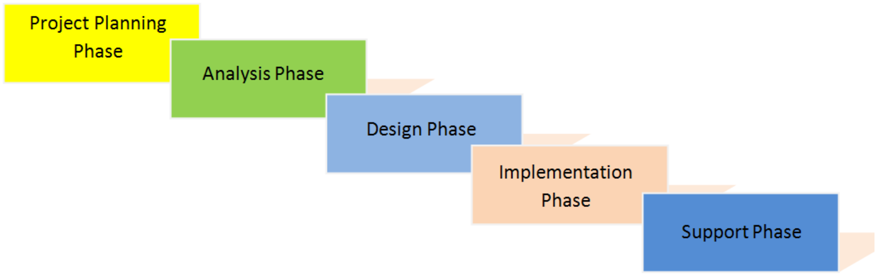

Figure 3.1 *Traditional Information System Development Phases*

As mentioned, the intention of this thesis is to build an interface connecting ANSI/ISA standards and SOA-oriented industrial system significantly, to refine the SDLC. To go detailed, the transmission from "As is" information to "To be" information (as mentioned in Chapter 2, in a master plan) looks up to the use of industrial standards. However, there is a still a lack of concrete applications to put the standard into practical use efficiently. On the other side, the information exchange also needs applications supporting the pre-defined frames and models. Two charts below explain the system in a comprehensive way.

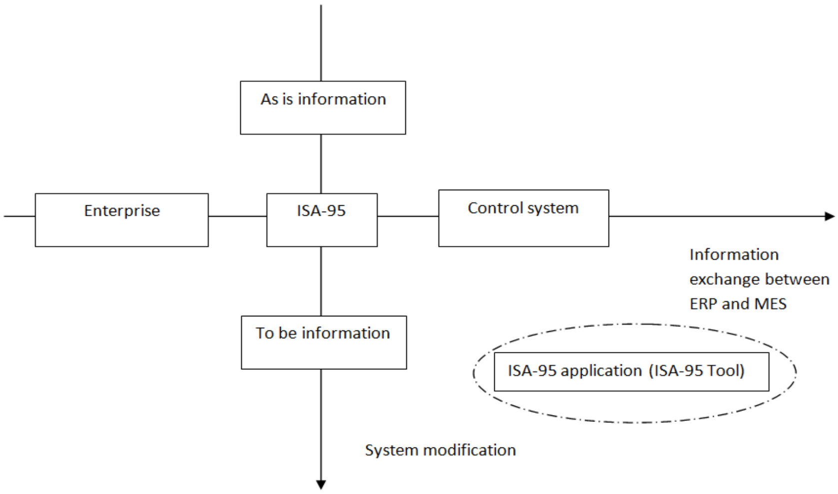

Figure 3.2 *the goal of ISA-95 Tool in system modification and information exchange between ERP and MES*

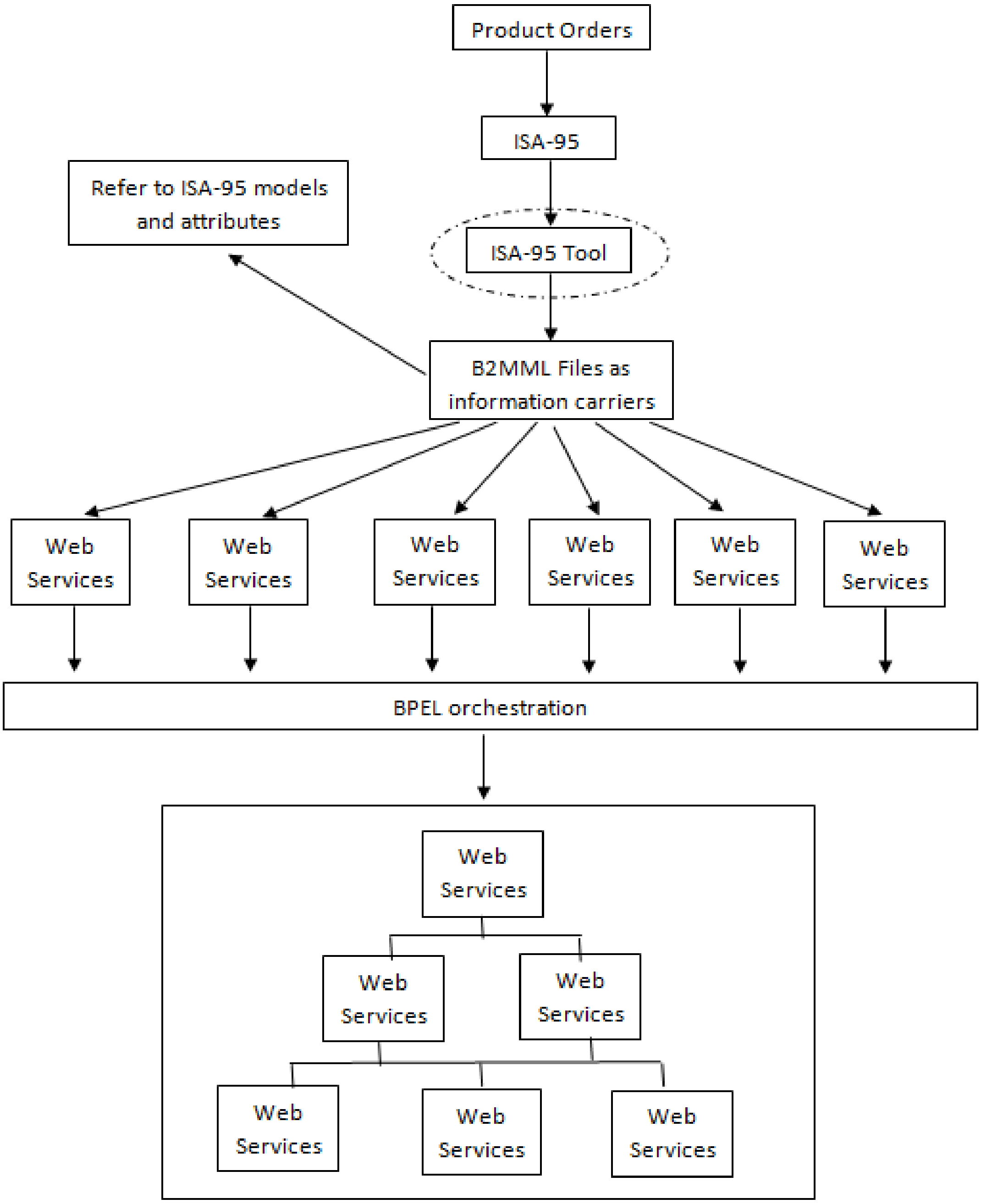

Figure 3.3 *an architecture of the work flow refining SDLC*

The initial goal of this thesis work is to create a solid application on analyzing information as product orders referring to ISA-95 and other materials as PERA. To be more detailed, in the very beginning of the industrial production, the production request are usually delivered in a format of order, which contains information as production requirements, manufacturing environment, etc. But due to the gap between enterprise and control systems, as defined as the interface between ERP level and MES level in ISA-95, the information exchange and other communication are not successfully preceded. Thus a complete set of models specifying the exchanged information are needed. In this thesis work ISA-95 is chosen as the reference standard of the object models and other specifications working on “filling the gap”. Also, the standard is proved (in PERA) to have the ability working as the reference making changes (e.g. updating) enterprise entities. However, as mentioned before, the models and attributes have large difficulties being accepted directly by industrial systems. Supportive application refers to the standard is necessary for the convenience both on enterprise and control systems` side. The software developed for this purpose in this thesis work, ISA-95 Tool caters the need by transferring production order (software input) to information understandable and digestible to control systems (software output). B2MML is chosen as the .xml implementation language thus a set of B2MML files carries the collected, specified information. The web services and operations in the network can be further processed for the working structure and higher efficiency. The process is called orchestration. However, the orchestration of the web services is not considered necessary in this thesis. More work related to web services can be part of the future work.

To identify the need for changes in enterprises and to carry out the changes expediently and professionally, as mentioned in former section of the thesis, the purpose of enterprise modelling is to provide such a discipline that organises all knowledge that is needed in the whole industrial procedure. To provide the company the necessary preliminary planning and operational guidance to be able to take full advantage of the above hardware and software developments, it is necessary to develop applications for industrial standards to fill the gap both for system modification and information exchange purposes (see *Figure 3.2).*

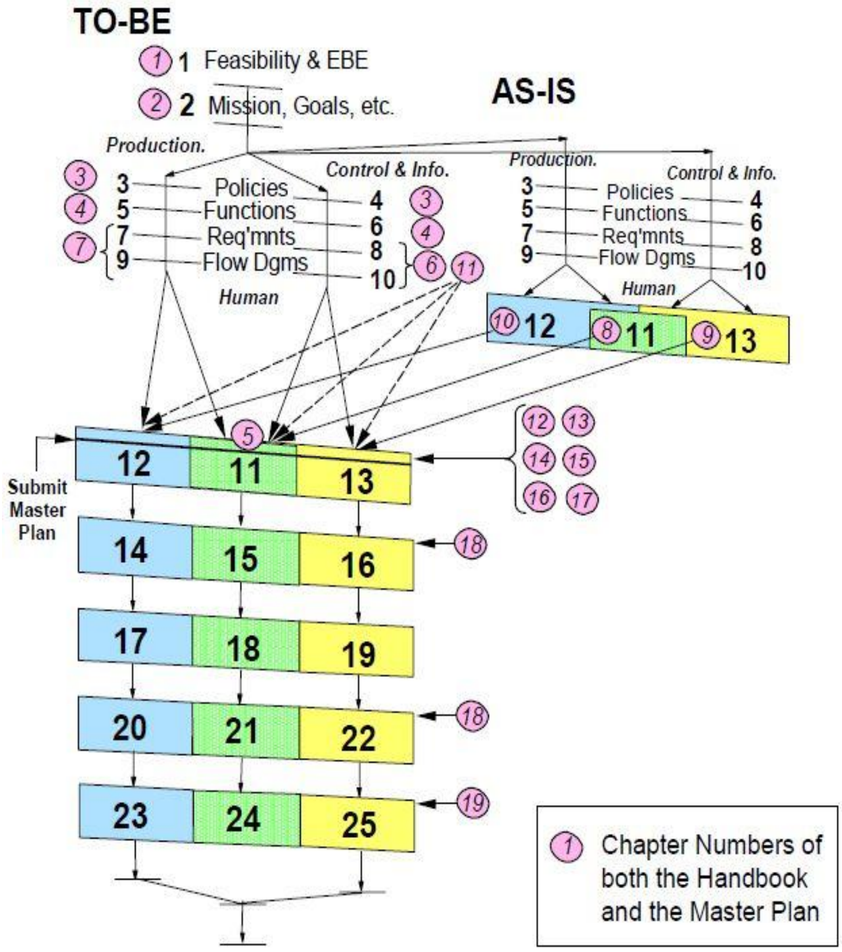

Figure 3.4 *detailed schedule in handbook on masters planning of PERA* [27]

3.2 Business activities in the application—Use case study of ISA-95 Tool

Use case diagrams serves as contents for the business events activities that must be supported by the system. It is used to identify the use cases to identify how the system will be used and which actors will be involved in which use cases. [8]

For this reason, use case diagrams and sequence models are depicted as part of the implementation together with ISA-95

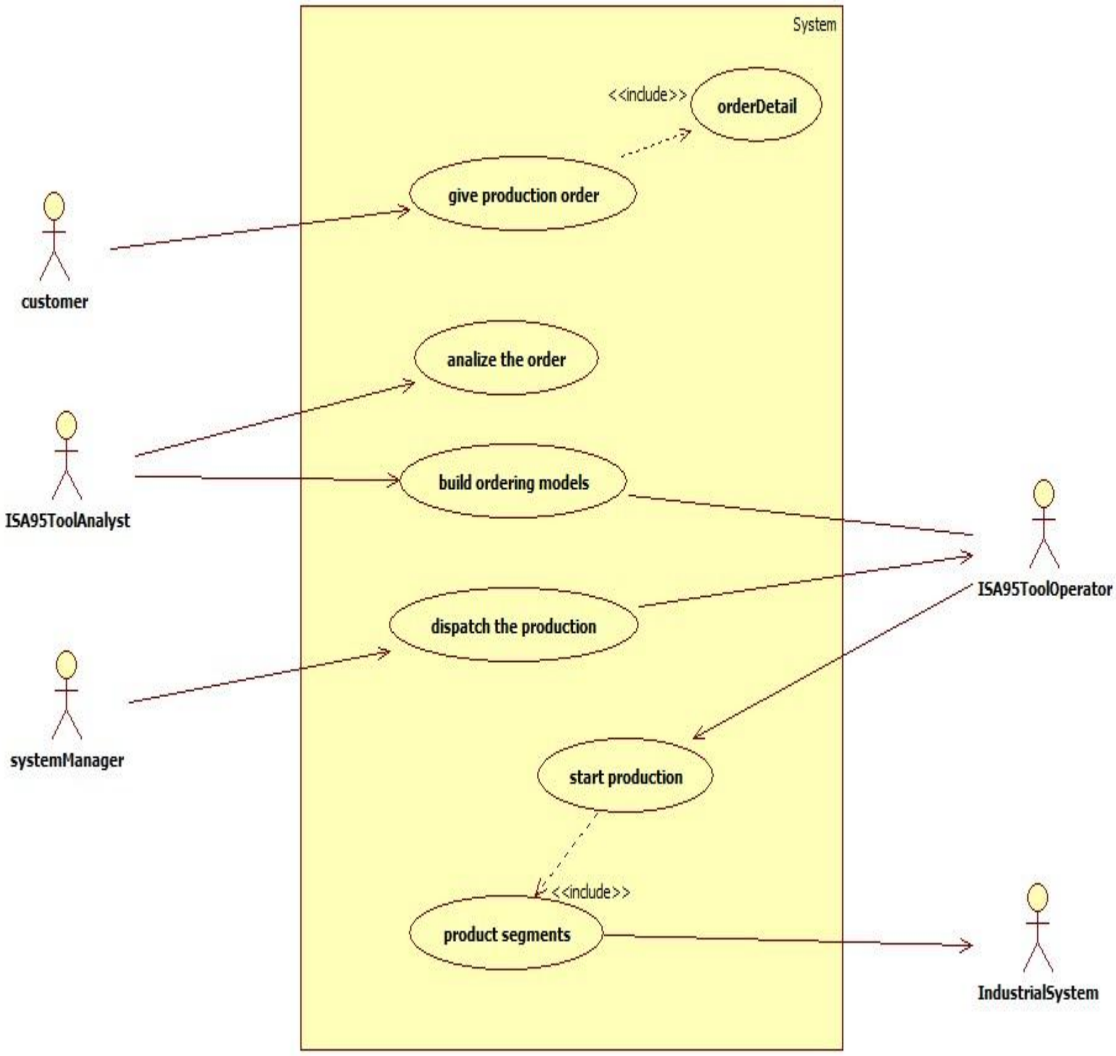

Figure 3.5 *Order Transferring Use Case Model for ISA-95 Tool*

ISA-95 is a toolkit, to go detailed, an interface for operations on industrial systems and it is designed to work with Web Service framework in an auxiliary way. It can also be used as a separated tool for placing orders to the line. The programming language for the software is Java.

As depicted in *Figure 3.5*Figure 3.5 Order Transferring Use Case Model, the event flow of the production starts from the customer setting production orders and ends with ISA-95 Tool completes product segments according to GUI inputs. The core carrier for the procedure is defined as “orders” in this project. For example, ISA-95 Tool engineers receive orders from customers. An order is transferred between ISA-95 Tool Analyst, system manager and ISA-95 Tool Operator and transformed into understandable and readable languages. Control system integrated in industrial systems will digest and execute the order to complete one process.

Creating use case diagrams is the only part of use case analysis. Careful system development requires more detailed level of description.

<table>
<tr><td>Use Case Name:</td><td colspan="2">Order Transferring Beyond GUI Level</td></tr>
<tr><td>Scenario:</td><td colspan="2">Create , transfer Orders & dispatch production</td></tr>
<tr><td>Triggering Event:</td><td colspan="2">Customer order products from FASTory Line</td></tr>
<tr><td>Brief Description:</td><td colspan="2">The customer calls an order of production, the FASTory Analyst and system verify order information, create and new order, add models to the order which are used by FASTory Operator. The operator start production after the system manager’s dispatching. The FASTory Line recognizes productions in unit of product segments.</td></tr>
<tr><td>Actors:</td><td colspan="2">Customer, ISA95ToolAnalyst, System Manager,
ISA95ToolOperator, IndustrialSystem</td></tr>
<tr><td>Related Use Cases:</td><td colspan="2">Includes: OrderDetail</td></tr>
<tr><td>Stakeholders:</td><td colspan="2">Business Contactor: for collecting customer information and providing introduction of IndustrialSystem</td></tr>
<tr><td>Preconditions:</td><td colspan="2">Customer must exist.
Personnel, equipment and material must exist for required items.</td></tr>
<tr><td>Postconditions:</td><td colspan="2">Order must be created.
Personnel, equipment and material must have the quantity on hand updated.</td></tr>
<tr><td rowspan="2">Flow of Events:</td><td>Actor</td><td>System</td></tr>
<tr><td>1. The customer gives a production order.
2. ISA-95Toolanalyst analyzes the order and builds specific UML models.
3. System manager dispatches the task.
4. ISA-95ToolOperator starts the operation according to the UML models.
5. IndustrialSystem runs in unit of segments.</td><td>1.1 setProductionOrder
2.1 checkCurrentOrder
2.2buildOrderingModels
3.1 dispatchProduction
4.1buildOrderingModels
4.2 startProduction
5.1 setGUIInput</td></tr>
<tr><td>Exception Conditions:</td><td colspan="2">1.1 If customer does not exist, the analyst pauses this use case.
2.1 If the order information is not sufficient for the production, the analyst can request for an update of the order.
4.1 If UML models (mainly ordering model) does not provide sufficient information or in wrong format, the operator can request for an update of the model.</td></tr>
</table>

Table 1 *Fully developed description for order transferring use case model*

While from the perspective of order placing, the order transferring can be set to 2 parts—the level beyond GUI (above the red line in *Figure 3.5*) and GUI level itself (under the red line in *Figure 3.5*. Here one extra use case model called "Interface operation model" is built for the second part. The model depicts the actions from setting GUI input to adding, cancelling or executing orders.

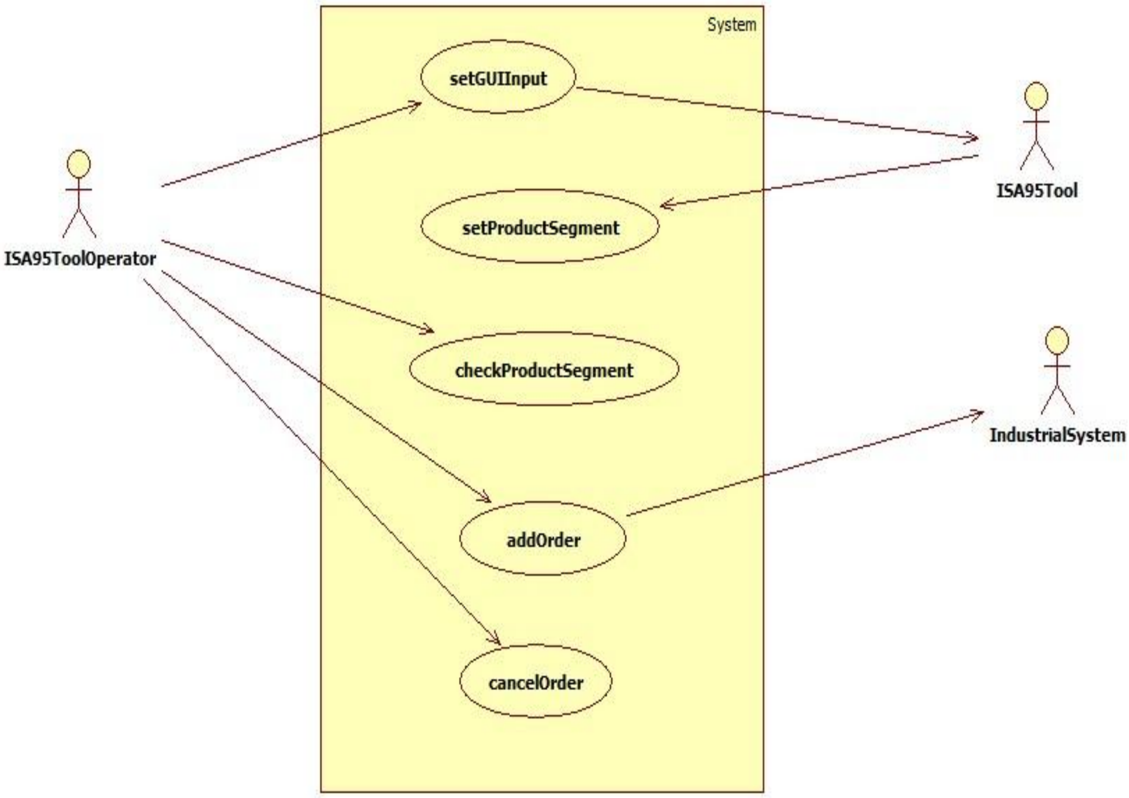

Figure 3.6 *Interface Operation Use Case Model*

An intermediate description is built for this model (see Table 2).

Flow of activities for ISA-95Tool Operation
Main Flow: 1. Set GUI input of screen style, frame style and keyboard style to ISA-95 Tool. 2. ISA95Tool output the product segment for the specified input. 3. The operator checks the demand of material, personnel, equipment, schedule, product style and other important information from product segment. 4. ISA95ToolOperator adds orders list after the correction of the mistakes (if any). 5. IndustrialSystem runs executes orders.
Exception Conditions: 1. If the order doesn't reach the requirement, the operator can delete the unwanted order in monitoring Block. 2. The operator can cancel the whole procedure by cancel of orders.

Table 2 *Intermediate description of ISA95Tool Operation Model*

3.3 Use case scenario study—Sequence Diagrams for ISA-95 Tool

A system sequence diagram (as SSD hereafter) is normally used in conjunction with the use case descriptions to help document the details of a scenario within a use case. [8] In most cases, sequence diagrams are used to explain object interactions and document design decisions.

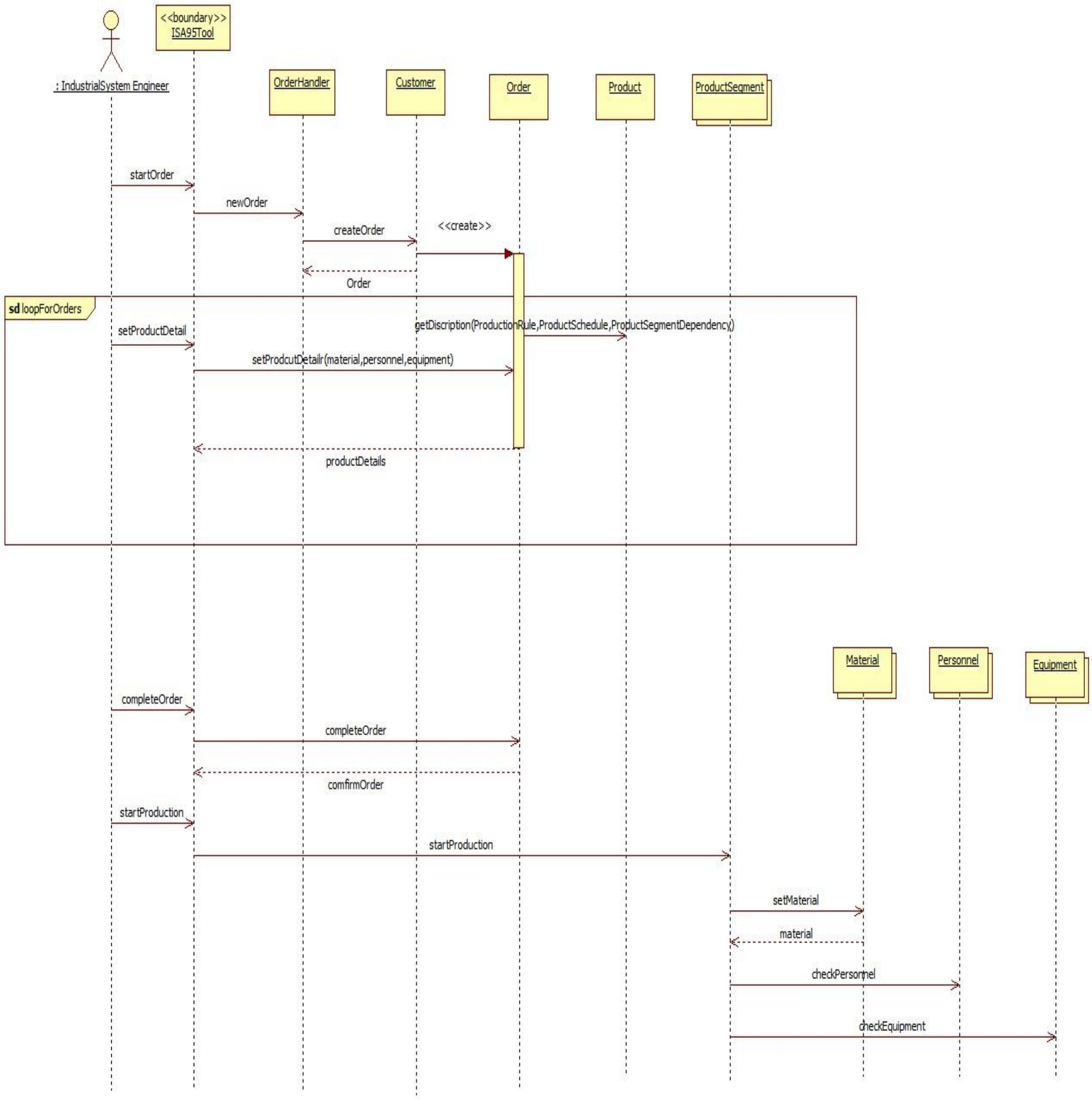

Figure 3.7 *Sequence model for ISA-95 Tool*

In this and the coming sequence diagrams, actors, actions and classes are defined in accordance with ISA-95.00.02 and the dimension of the classes should be the same with object models mentioned in Chapter 3 in this paper work.

The difference is, in the level beyond problem domain, IndsutrialSystem Engineer starts an order from an order query system, which is not included in use case diagrams.

While the system boundary of the 2nd sequence model, is set at the start point of the problem domain. The work of getting orders as input and transforming it into “problem domain” is completed in this level by ISA-95 Tool.

3.4 Extensions of relevant general models

Admittedly, the industry currently supports many methodologies that define formal procedures specifying the process of gathering, analyzing applications’ requirements and incorporating them into a program design. But still the complexity is very high. One characteristic of UML—also the one enables the widespread industry support that the language enjoys-is that it is methodology-independent.

The design of the following object models are based on basic knowledge of industrial system manual books. As we know, several different projects may be required in case of developing and updating the original system later. The building of models must consider multiple levels of applications and face varying requirements from consumers to maximize the benefit. While in this thesis, in fact also in most of the researches, modeller focuses on the initial development project and not on the supporting projects [8]. In other words, the primary concern of the thesis is to get an industrial system operated and operated the very first time.

ISA-95 standard book also gives reference for expanding the classes. For example, in 7.3.2.1 in ANSI/ISA-95.00.01, it defines personnel class as follow:

“A personnel class is a means to describe a grouping of persons with similar characteristics for purposes of scheduling and planning. Any person may be a member of zero or more personnel classes [36].”

Examples of the objects in a class in given:

Examples of personnel classes are “cook machine mechanics,” “slicing machine operators,” “cat-cracker operator,” and “zipper line inspectors”.

As one of the possible scenarios in industrial systems, the extension of personnel class is visualized by the generalization between “operator” class, “engineer” class and “personnel class” (*Figure 3.8*). This structure shows the taxonomic relationship between a more general element (the parent—personnel class) and a more specific element (the child class—operator, engineer) that is fully consistent with the first element and that adds additional information.

Also, the associations between 2 child classes and the qualification tests are built.

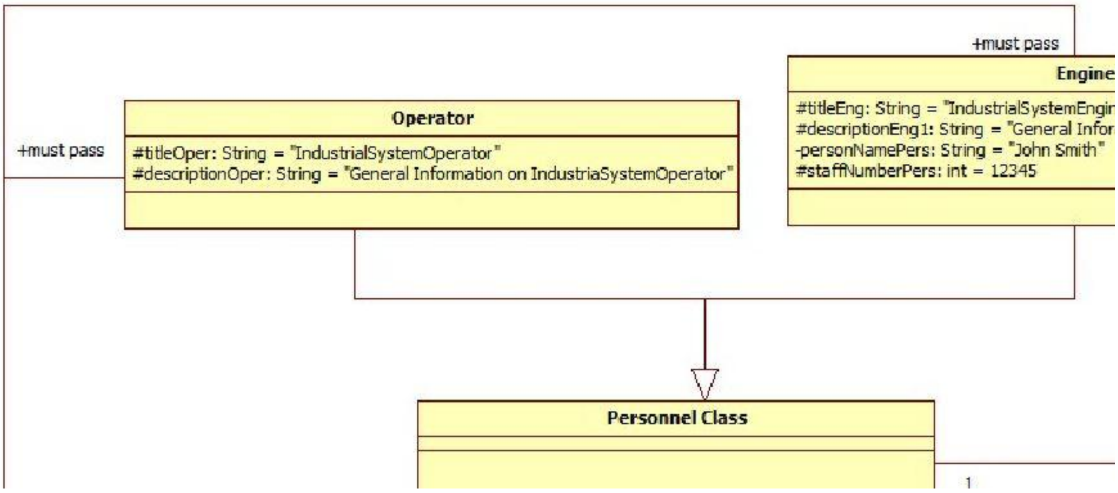

Figure 3.8 *an example of extension of Personnel Class for Industrial System*

Another issue worth being mentioned is that in most of the cases, attributes have large flexibility. As indicated in Table 1, the title or even the data type can contain different variation.

Attribute Name	Description	Examples
ID	An identification of the specific property.	Class 1 Certified
		Exposure Hours Available
		Pager Number
Description	Additional information about the *person property.*	"Indicates if the person is Class 1 certified widget assembly operator"
		"Indicates number of exposure hours available this month"
		"Pager number"
Value	The value, set of values, or range of the property. The value(s) is assumed to be within the range or set of defined values for the related *personnel class property.*	True
		4
		800-555-1212
Value Unit of Measure	The unit of measure of the associated property value, if applicable.	Boolean
		Hours
		phone number

Table 3 *an example of person property attributes*

UML notation used in the models is attached as Appendix 4. The general models and description on the models built for the 2 lines are as follow:

3.4.1 Personnel Model

The personnel model contains the information about specific personnel, classes of personnel, and qualifications of personnel.

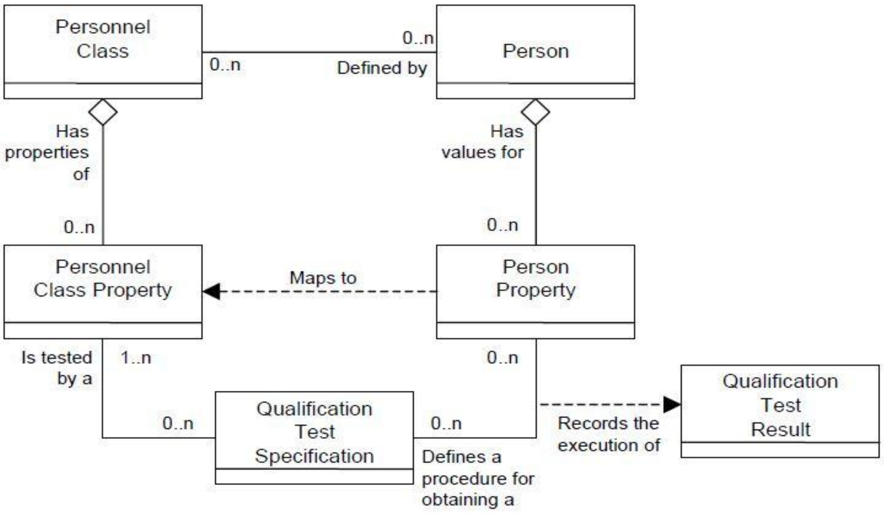

__Figure 3.9__ Personnel model

And with FASTory-Line's high level of automation, the requirements for personnel are comparatively low. Some of the attributes in this part can be left blank.

3.4.2 Equipment Model

The Equipment model contains the information about specific equipment, the classes of equipment, equipment capability tests, and maintenance information associated with equipment.

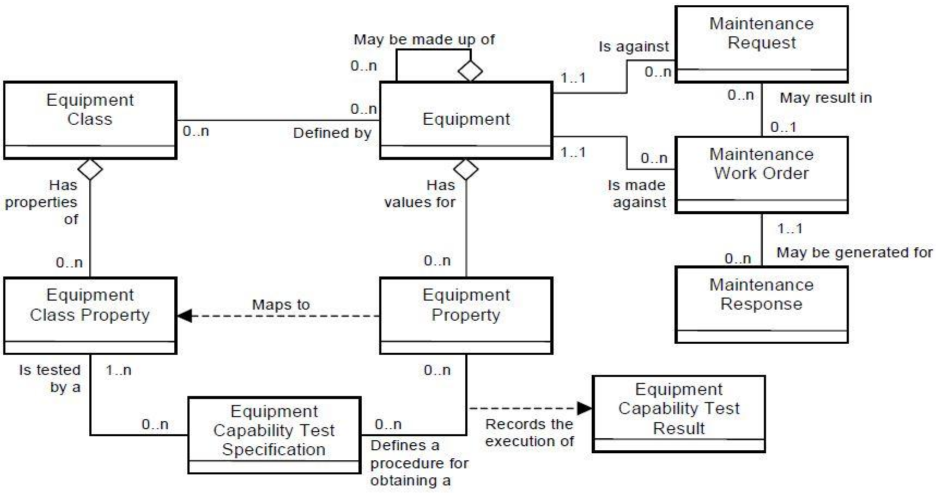

__Figure 3.10__ Equipment Model

3.4.3 Material Model

The material model defines the actual materials, material definitions, and information about classes of material definitions. Material information includes the inventory of raw, finished, and intermediate materials. The current material information is contained in the material lot and material sublot information. Material classes are defined to organize materials.

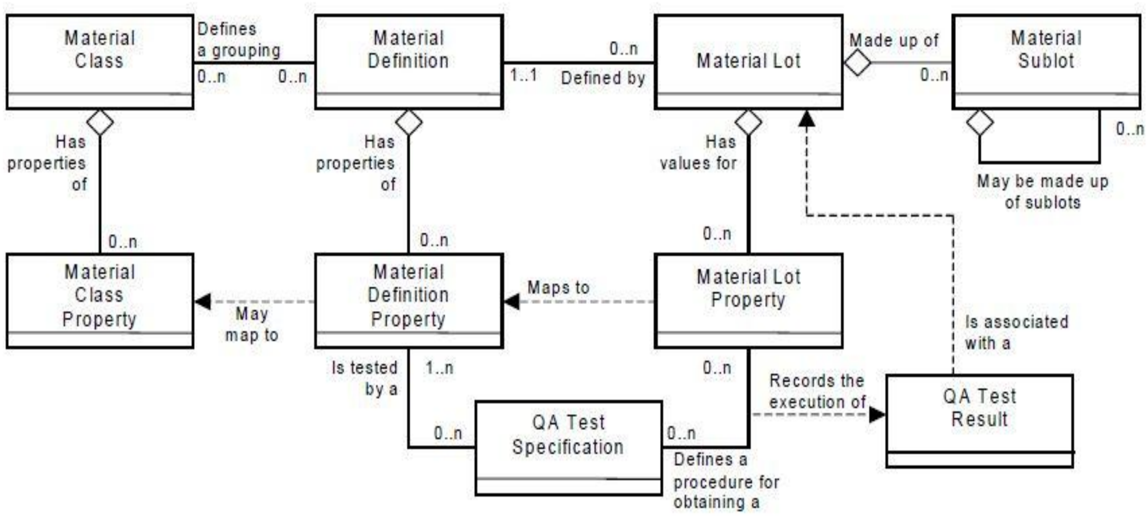

Figure 3.11 *Material model*

The expression of data should be in accordance with consumers' requirements. E.g., the colour here can be called red, green and blue directly. But for a higher resolution, the entity can also be called by its hue and saturation.

The material model built for FESTO Line defines the actual materials, material definitions, and information about classes of material definitions. Material information includes the inventory of raw, finished, and intermediate materials. The current material information is contained in the material lot and material sublot information. Material classes are defined to organize materials. In this material model, the generalization relations between "material class" and classes as "spring", "piston" are expressed by arrow lines. And so is the generalization of "material lot class" and classes as "SilverCylinder", "BlackCylinder" and so on.

3.4.4 Production Capability Model

The production capability information is the collection of information about all resources for production for selected times. This is made up of information about equipment, material, personnel, and process segments. It describes the names, terms, statuses, and quantities of which the manufacturing control system has knowledge. The production capability information contains the 'vocabulary' for capacity scheduling and maintenance information.

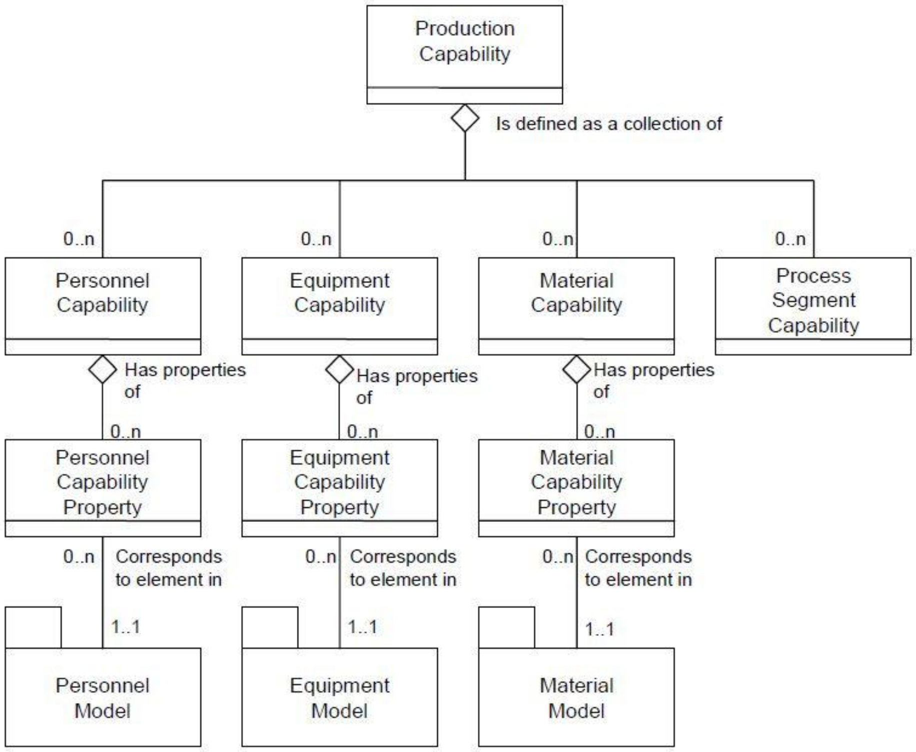

Figure 3.12 *Production capability model*

In this model, where persons are members of multiple personnel classes then the personnel capability information defined by personnel class should be used carefully because of possible double counts, and personnel resources should be managed at the instance level.

Obviously, the personnel capability attributes defined here, double counts with personnel classes and there are no significant differences between them。So this object should be deleted or ignored.

Moreover, take the personnel capability attributes as an example, when attributes as “Capability Type”, “Location” and “Reason” are the same as that in Production capability attributes, they should also not be counted in. ISA-95.00.02-2001 Annex A shows simplified examples of multiple models in practical use.

3.4.5 Process Segment Model

A process segment is a logical grouping of personnel resources, equipment resources, and material required to carry out a production step.

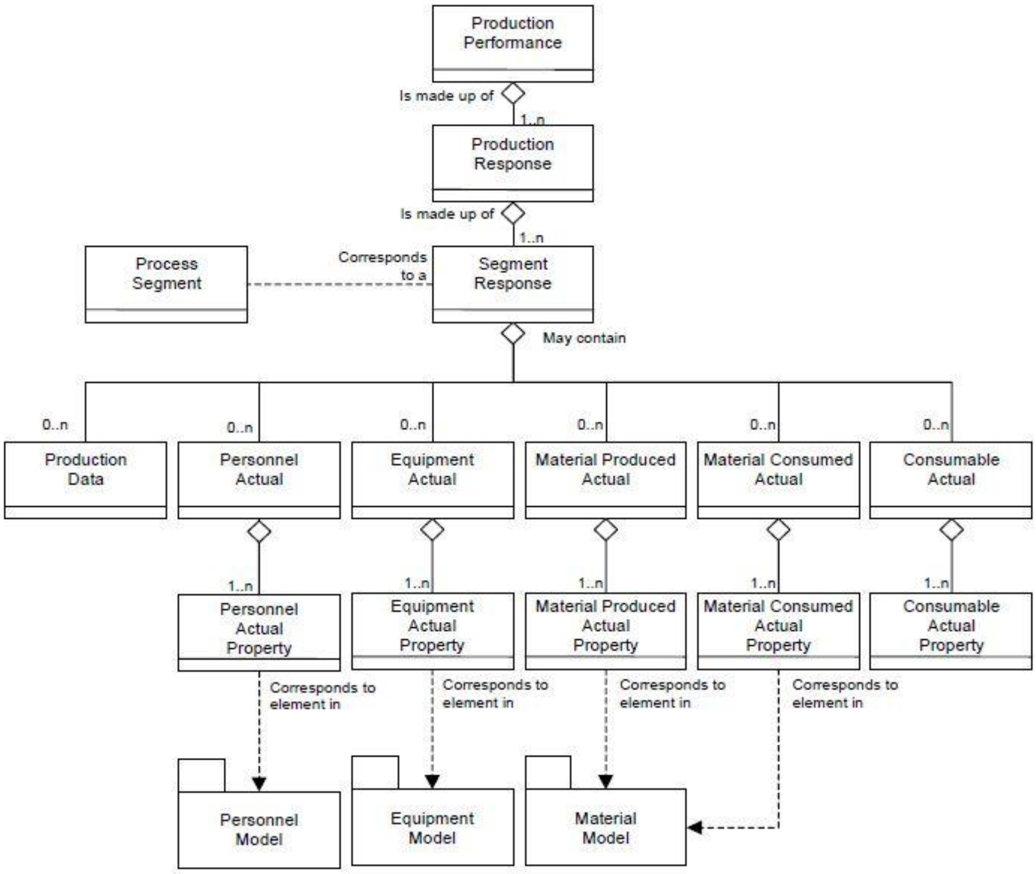

Figure 3.13 *Process Segment Model*

3.4.6 Process Segment Capability Model

A process segment capability is defined as a logical grouping of personnel resources, equipment resources, and material that is committed, available, or unavailable for a defined process segment for a specific time. It is related to one or more than one products segment that can occur during production.

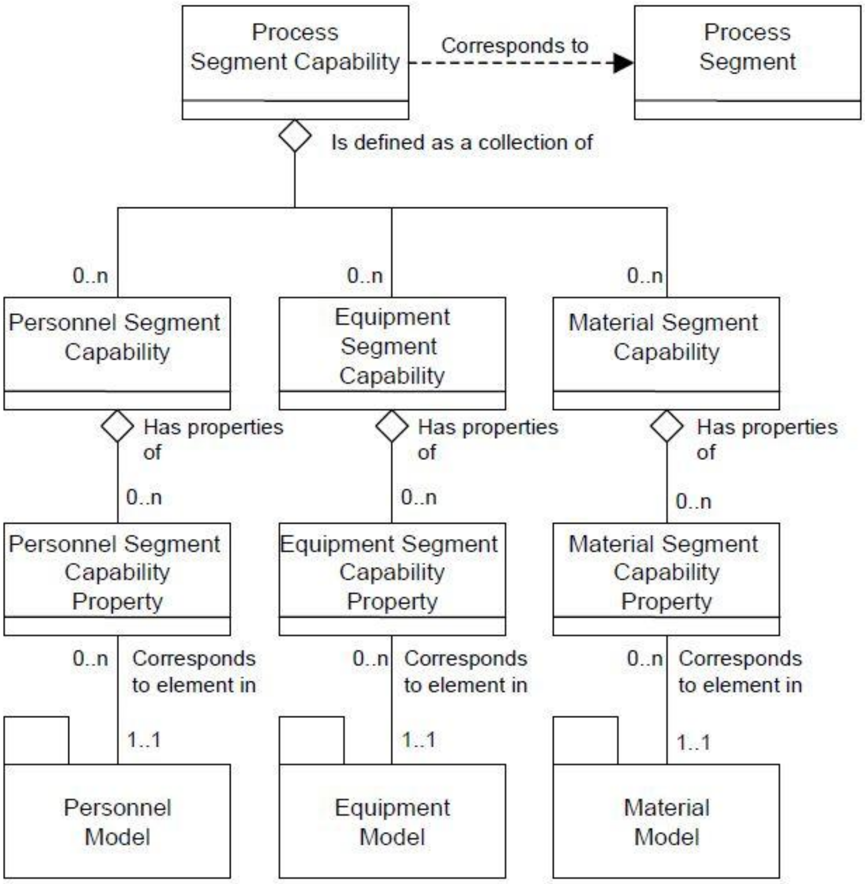

Figure 3.14 *Process segment capability for FASTory Line*

For presenting the change of the process segments between "AS-IS" and "TO-BE", 2 separate process segment models are built for the production lines. The 2 process segment models contains also majority of the information for both of the systems and the transformation.

3.4.7 Production Schedule Model

Production information is defined in two model correspond to requests for production and responses to the requests.

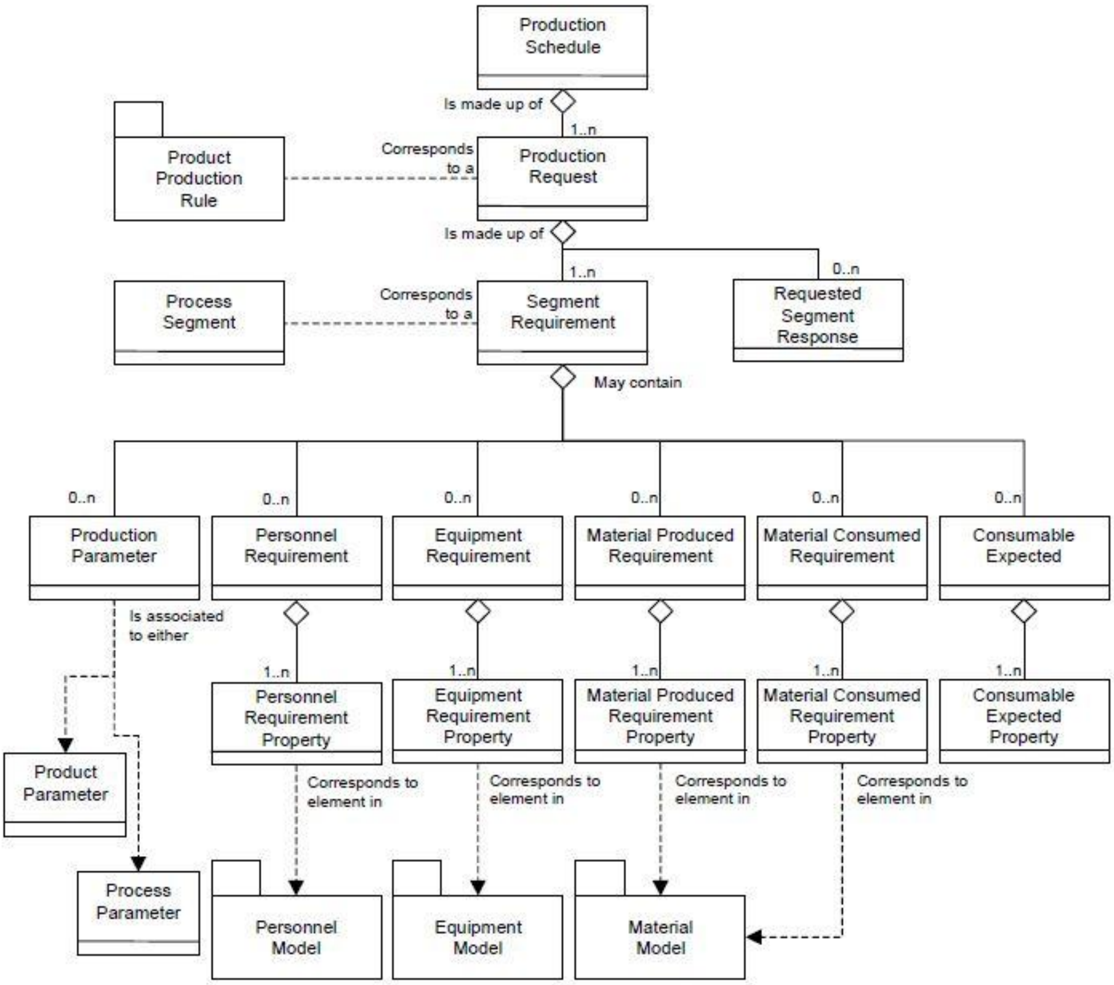

Figure 3.15 *Production schedule model*

There are multiple segments defined in the example. There is one master segment of production that applies to the entire production request. The master segment is made up of multiple nested segments for individually specified and reported segments of production [37].

The rest parts attributes in the model, including personnel requirement and its property, equipment requirement and its property, material produced requirement and its property, material consumed requirement and its property, consumable expected and its property are not necessary.

3.4.8 Production Performance Model

The performance of the requested manufacturing requests is the production performance. Production performance is a collection of production responses.

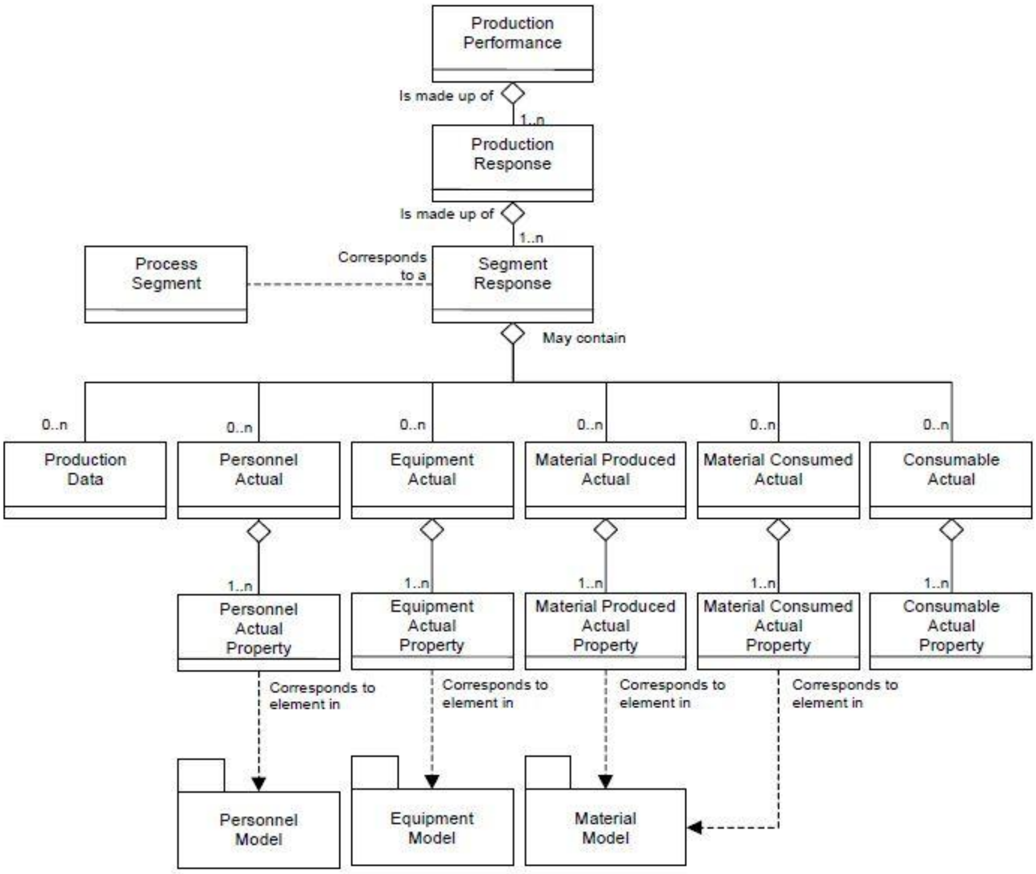

Figure 3.16 *Production Response Model*

There are multiple segments defined in the example. There is one master segment of production that applies to the entire production response. The master segment is made up of multiple nested segments for individually reported segments of production [38].

3.4.9 Product Definition Information Model

The product definition information is information shared between production rules, bill of material, and bill of resources.

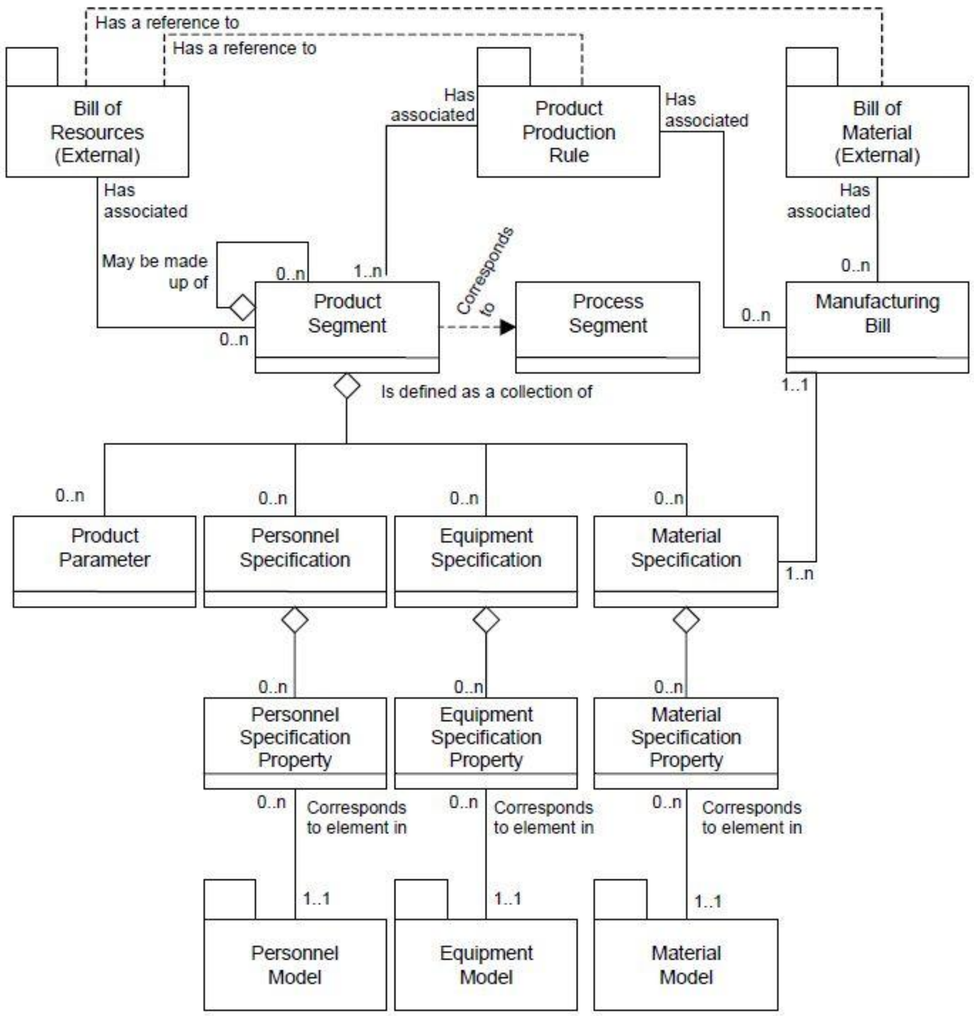

Figure 3.17 *Product definition model*

FASTory Line is still in development state, some actual data can only be got after it’s fully tested. As a result, the attributes of personnel actual attributes and personnel actual property are to be announced.

4. Industrial System Case Studies

4.1 Industry system development trends

Software Intensive Industrial System can be seen all the software intensive system (as SIS hereafter) for industrial use.

The first IEEE (Institute of Electrical and Electronics Engineers) definition of SIS comes in July, 2007 in "IEEE Recommended Practice for Architectural Description of Software-Intensive Systems":

A software-intensive system is any system where software contributes essential influence to the design, construction, deployment, and evolution of the system as a whole.

We are in a world with diversity of devices, software, and high degree of connectivity in complex systems. A new era has sent its invitation from every corner of the world and in any known format. The humans are on their way catching these god-speed steps. As mentioned in "A Science of Design for Software-Intensive Systems" by Peter Freeman and David Hart, changing this situation will not happen overnight, but it is also not possible to wait for another three decades.

Attendees at the 1968 NATO Software Engineering Conference in Garmisch, Germany, built a foundation for the systematic creation of SIS [35]. Scientists have realized how essential to create these systems based on a set of efforts and the process have continued since then to develop a scientific basis for expanding this platform.

While for computer scientists, being told the difficulty of creating software-intensive systems is not news. In the article of "Why software falls" [1], it mentions that the success degree for SIS development is only 35%.

One of these problems is, individual who activates own intellectual capabilities can take the complexity of some design tasks. Human intelligence is limited and additional intellectual support is needed. So there are bases to agree that designers need instrumental means which can give us a real time access to intellectual resources of the corporate network. [36]

There are also different argues that a high percentage of failures in software development are not due to bad capabilities of technicians but to deficiencies in used methods. Like practically every article dealing with these problems in the popular press, is cited "poor management" as the cause in referenced GAO report and lists more than 10 detailed reports to support the case. Specifics cited in this and the underlying reports attribute failure to implement "a process for selecting, prioritizing, controlling, and evaluating the progress and performance of all major information systems and investments, (including specifically) disciplined, consistent procedures for software requirements management, quality assurance, configuration management, and project planning and tracking." Among these, the deficiencies in configuration management and quality assurance are not the root of the failure to meet the system objectives. Of greater importance are persistent problems in requirements management and system effectiveness assessment in all development phases [37].

Thereby, to enhance the productivity and quality of software intensive organizations it is essential to introduce seamlessly efficient management and engineering practices [38]. Since methods, models [36] and languages focus on partial optimization in a system; here a larger concept is needed, a standard system to rule the innovation. The solution chosen in this thesis work is ISA-95.

4.2 Study case—FESTO Line

FESTO line in FAST Lab can be seen as a modified version of Multi FMS line which keeps all the functionalities (except for turning). It contains 10 equipment devices: Milling FMS Station, conveyor, Distributing Station, Testing Station, Processing Station, Handling Station, Robot Station, Assembly Station, Sorting Station and ASRS (Automatic Storage and Retrieval System) Station. [40]

Figure 4.1 *FESTO line (1)*

Each station has its own controller, which means that each station can also be used on its own. Synchronisation of the individual stations is performed via digital I/O at level 1 (L1).

Figure 4.2 FESTO Line (2)

A second communication level (L2) for transferring data to the two computers at the control level can be installed in addition to and independently of level 1. Profibus or Ethernet is used here. Level 2 is not required for operation of the system; however it does increase its ease of use.

The system is designed to process cylindrical parts. Different programs are necessary for the CNC-machines. At the moment 5 programs for each CNC-machine are integrated. It is also possible to create new programs for other parts. Another difference is the material, aluminium and brass are available.

The system consist of two CNC- machines CONCEPT MILL105, CONCEPT TURN105 a RV-3SB robot, a linear axis and the commissioning station.

There is no PLC-Controller; all control orders which are necessary for operation are executed from the Drive unit of the robot.

Distributing process

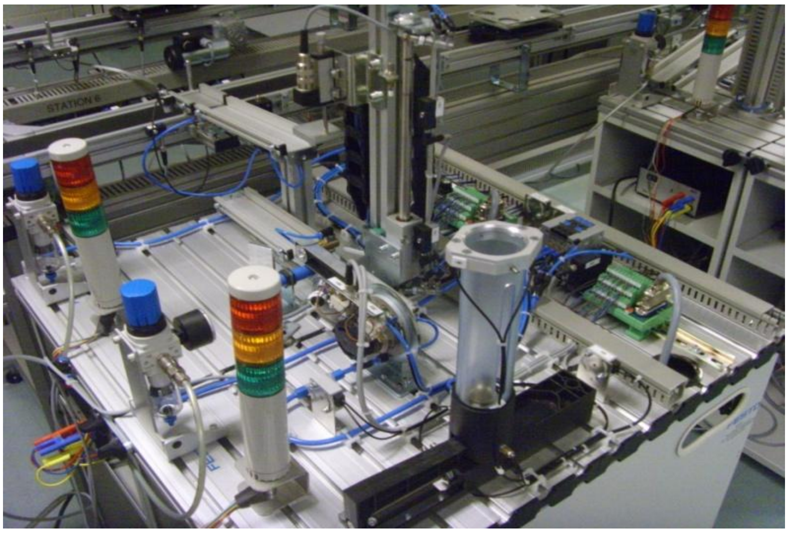

Figure 4.3 *Distributing and Testing Station (1)*

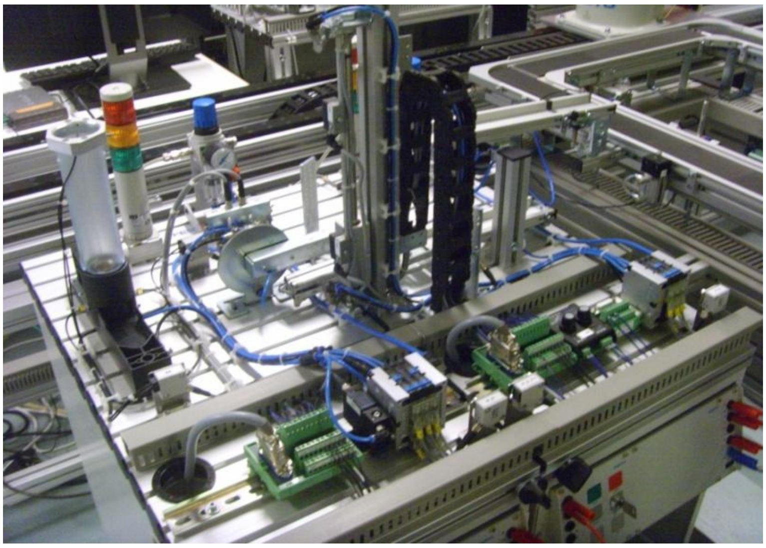

Figure 4.4 *Distributing and Testing Station (2)*

For the distributing process, the station separates work pieces from the stack magazine module.

The filling level of the stack magazine is monitored by means of a through-beam sensor. A double-acting cylinder pushes out the work pieces individually. The Changer module grips the separated out work piece using a suction cup. The arm of the transfer unit, driven by a rotary drive, conveys the work piece to the transfer point of the downstream station.

Testing process

For the testing process, the station determines the characteristics of the work pieces received by the previous station, in this case the Distributing station.

The sensing module identifies the colour of a work piece and a capacitive sensor detects each work piece regardless of their colour. A diffuse sensor identifies metallic and red work pieces. Black work pieces are not detected by the diffuse sensor. A retro-reflective sensor monitors whether the area above the work piece retainer is free before the work piece is lifted by the lifting module. The analogue sensor of the measuring module determines the height of the work piece. The output signal is digitalized via a comparator with adjustable threshold value. A linear cylinder guides the correct work pieces to the downstream station via the upper air cushioned slide. Other work pieces are sorted on the lower slide.

Processing process

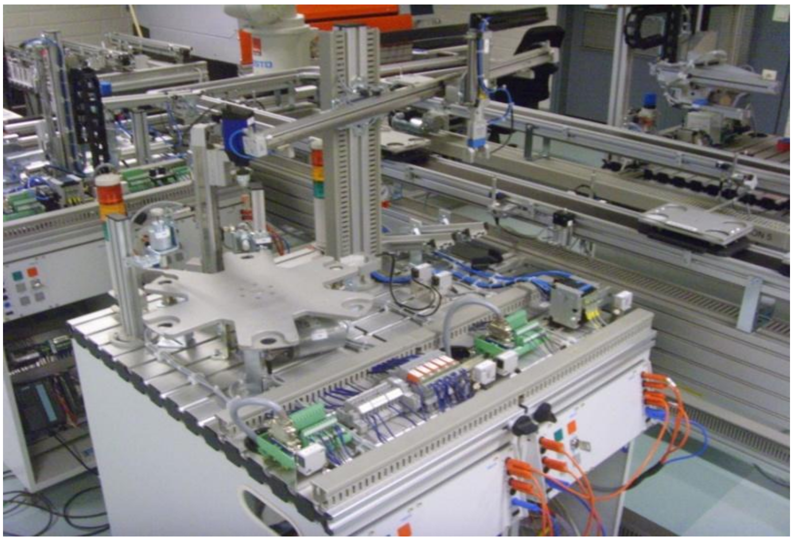

Figure 4.5 *Processing and Handling Station (1)*

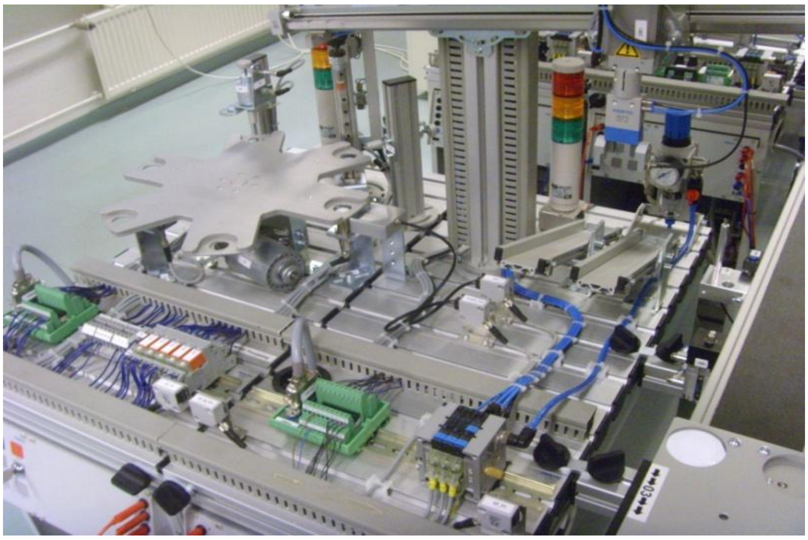

Figure 4.6 *Processing and Handling Station (2)*

For the processing process, the station checks the characteristics of work pieces, machines work pieces and supplies work pieces to a subsequent station.

Work pieces are tested and processed on a rotary indexing table. The rotary indexing table is driven by a DC motor. The table is positions by a relay circuit, with the position of the table being detected by an inductive sensor. On the rotary indexing table, the work pieces are tested and drilled in two parallel processes. A solenoid actuator with an inductive sensor checks that the work pieces are inserted in the correct position. During drilling, the work piece is clamped by a solenoid actuator.

Finished work pieces are passed on via the electrical ejector.

Handling process

For the handling process, the handling station is equipped with a flexible two-axis handling device.

Inserted work pieces are detected in the retaining device by an optical reflex light sensor.

The handling device fetches the work pieces from the retaining device with the help of a pneumatic gripper which is fitted with an optical sensor. The sensor differentiates between ‘black’ and ‘non black’ work pieces. Workipieces can be deposited in different slides on the basis of these criteria. Other sorting criteria can be defined if the station is combined with other stations. It is possible to transfer work pieces to a subsequent station.

Robot station

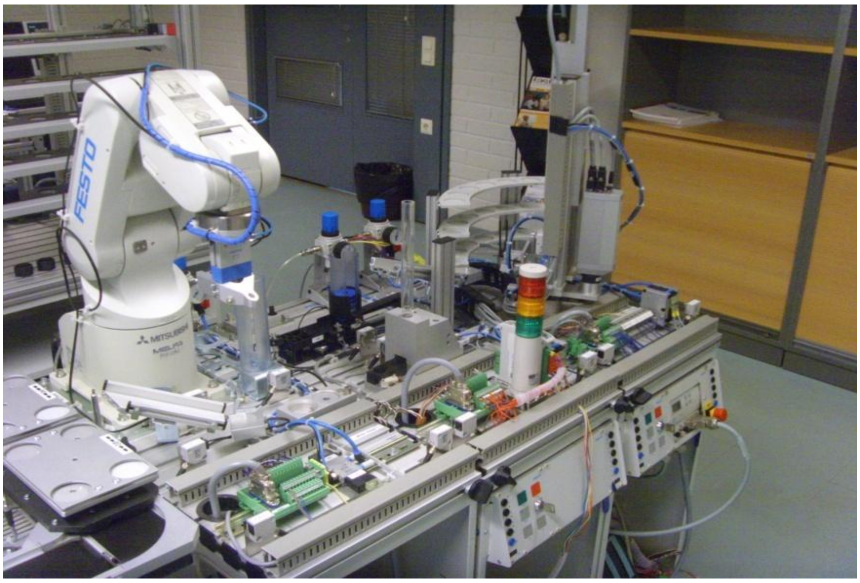

Figure 4.7 *Robot Station*

For the robot station, it assemblies work pieces or separates red/metallic and black work pieces

Work pieces are transported by means of a slide on the retaining device.

The robot fetches the work piece from the retainer device with the help of a pneumatic gripper. The work pieces are deposited on the assembly retainer. By means of an optical sensor the orientation of the work piece is checked. An optical sensor is fitted to the gripper jaw. This sensor differentiates between black and non-black work pieces. The worpieces can be deposited into different magazines on the basis of these criteria. It is also possible to transfer work pieces to a subsequent station. In combination with the Assembly station the component parts of a short-stroke cylinder are assembled into a functional cylinder.

Assembling process

For assembling process, the station supplies work pieces for the Robot station. The body of the pneumatic cylinder for assembly is fed to the robot via a slide. The robot fetches the body and places it to the identification position of the Assembly retainer module. An optical sensor is fitted to the gripper jaw. This sensor differentiates between black and non-black bodies. The robot establishes the orientation of the body and places it in the correct orientation in the assembly position of the Assembly retainer module. Depending on the colour of the body the robot takes a piston from the pallet an inserts it into the body. For red and metallic bodies black pistons are used. For black bodies metallic pistons are used. Afterwards the piston spring is inserted. The cap is picked up at the Cap magazine module. The robot establishes the orientation of the cap and places it in the correct orientation on the body. The finished pneumatic cylinder is placed on a slide.

ASRS Process

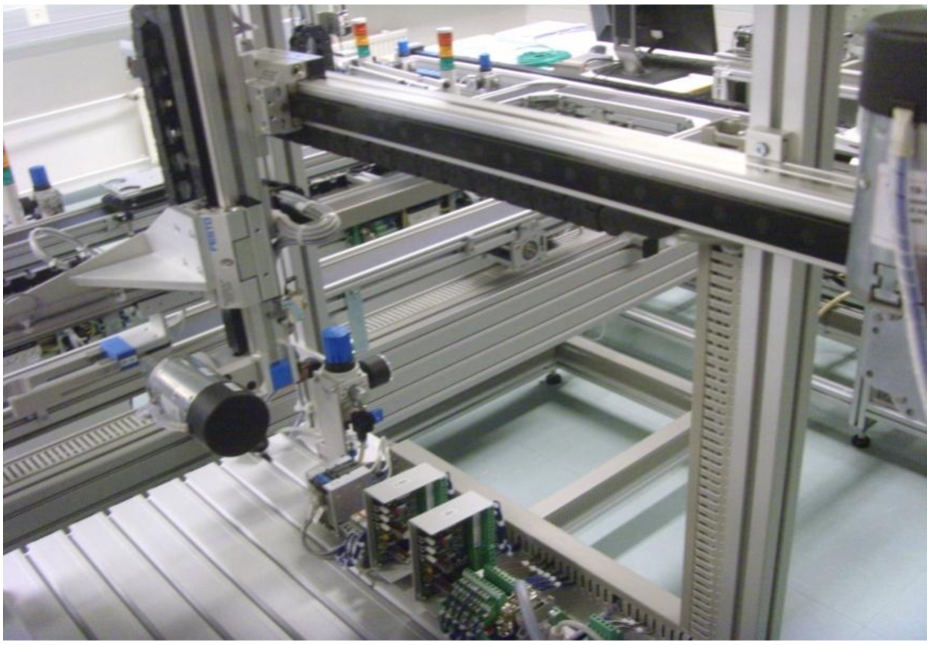

Figure 4.8 *ASRS Station (1)*

Figure 4.9 *ASRS Station (2)*

For the ASRS Process, a shelf and a transporting beam is used for this station. The classification of the storage and retrieval can be visualized by different programming.

Sorting Process

The Sorting station sorts work pieces onto three slides. Work pieces placed on the start of the conveyor are detected by a diffuse sensor. Sensors upstream of the stopper detect the work piece features (black, red, metal). Sorting gates actuated by short-stroke cylinders via a deflector allow sorting of work pieces onto the appropriate slides. A retro-reflective sensor monitors the level of the slides.

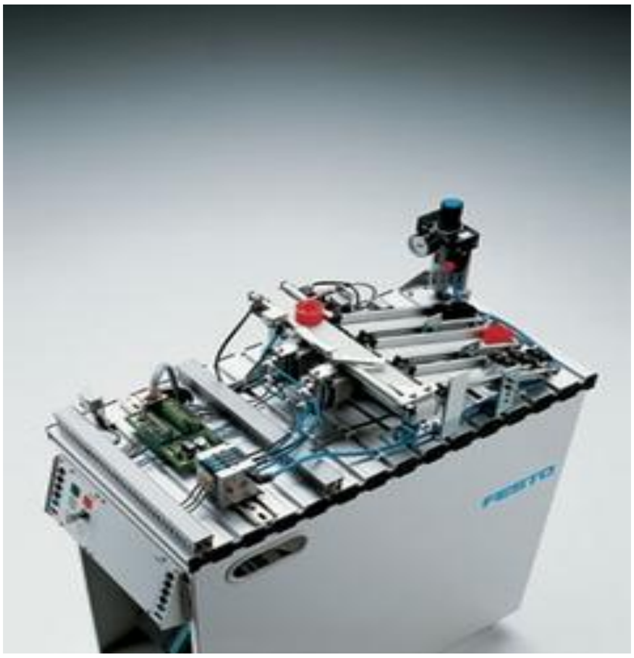

Figure 4.10 *Sorting Station*

Conveyor

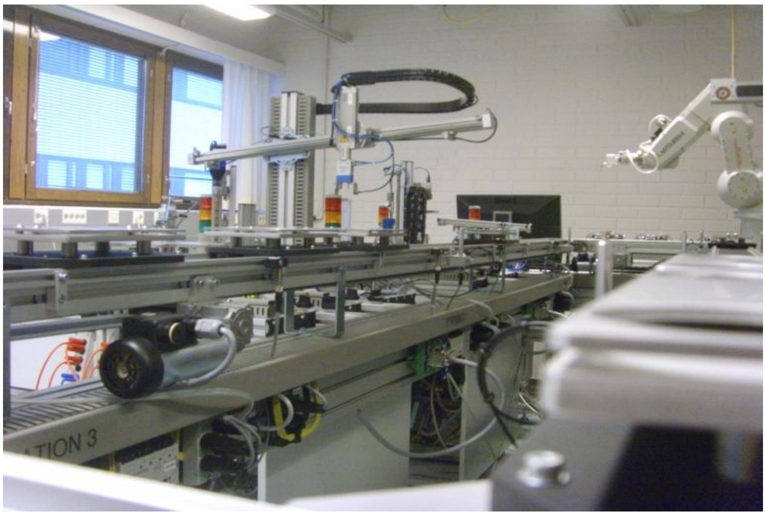

Figure 4.11 *Conveyor of FESTO line*

For the Conveyor, it transfers half-processed components between stations. Several pallet holders are used as the carrier of the components. 5 out of 8 stations' portal are connected to the conveyor.

PC1: For visualising and operating the MPS® system [41]

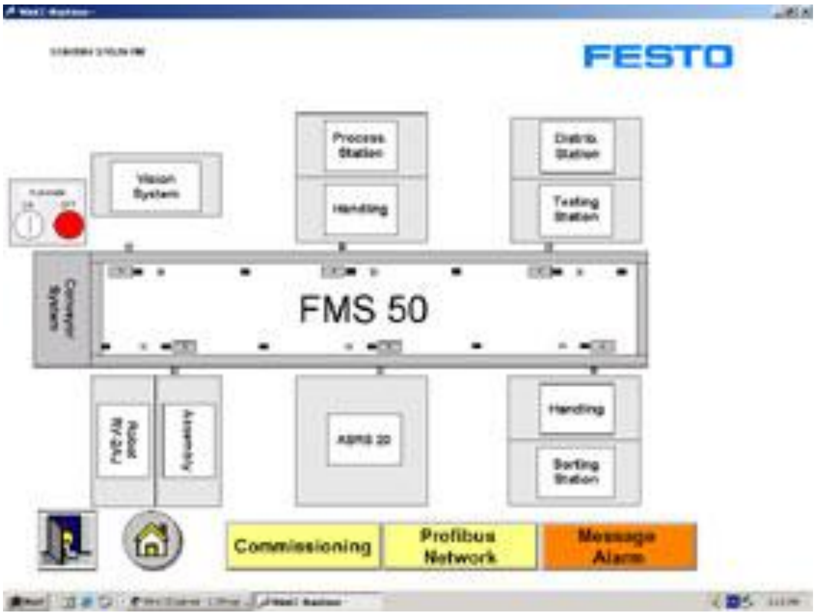

Figure 4.12 *FESTO Line PC No.1*

In practice, almost all large production systems are equipped with a system visualisation feature. System visualisation and operation of the assembly line are provided on the basis of WinCC or InTouch, depending on the PLC used in the system, as an optional extra for FESTO Line.

PC2: Order input and visualisation of the CNC cell

Figure 4.13 *FESTO Line PC No.2*

The cell computer (PC2) of the CNC cell facilitates input of a number of different CNC orders in one order batch. Each order can start its own CNC program via DNC. You can also define whether an order should involve turning or milling or turning and milling. In addition to order input, the CNC is dynamically visualised using a 3D representation.

4.3 Study case—FASTory

FASTORY-Line is a assembly line used for research purposes. In order to simulate the production, drawings are done by robots. Its main advantage is that it can make different drawings (to simulate parts of an assembly) and also different colours of ink can be used to increase the complexity of the systems as well as production customization.

Figure 4.14 *FASTory-Line*

The drawing consists of 3 parts: frame, screen and keyboard; there are 3 different models for each part and 3 different pen colours (red, green and blue). The product has 729 variants. All the drawing robots are able to draw all the parts, it allows to make the complete mobile phone or just one part to give some flexibility to the line. The material to be used in the production will be paper and pens for the drawings.

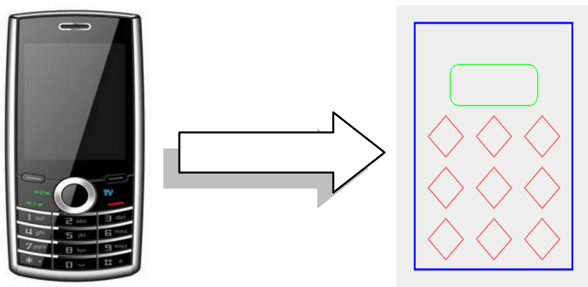

Figure 4.15 *Mobile drawing*

The production line is composed by 11 robotic cells and one static buffer. Each robotic cell is composed by an SCARA robot, a pen feeder, and 2 conveyors. 10 of the cells are used for drawing and one for input/output of material.

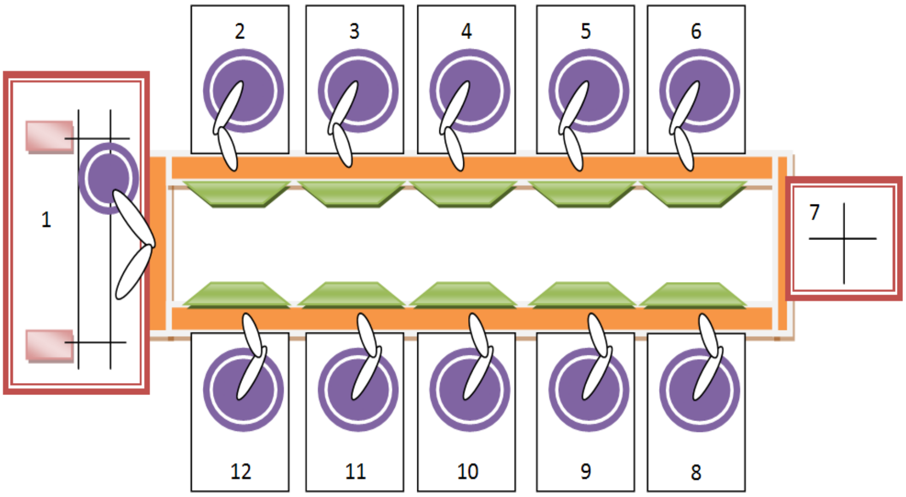

Figure 4.16 *Line Flow (2)*

The pallet goes through the conveyors to the robotic cell and when the pallet arrives to the working area it stops. After waiting for the robot to do the work, the pallet continues thought the line going to the other robots.

Figure 4.17 *Manufacturing Cell [39]*

The pallets go around the line passing from conveyor to conveyor. The pallet starts in the cell on the left and goes through the line and ends in the same cell. The robots in the cells draw the frame, screen and keyboard in the pallet and a mobile phone figure is in the paper at the end.

Sufficient description for the connection including the architecture, the equipments, data flow, and the models will be presented in Part 3.

5. Implementation

5.1 Object Models built for study cases

In Chapter 3, use case diagram and sequence diagram are made for the describing ISA-95 Tool that is a basis for information models creation for SIIS following specific B2MML (open) format in implementation phase. Also, the principles of generalized model extension are explained. In this chapter, the object models for the study cases are built (summarized in *Appendix 5* to *Appendix 17*) as part of the implementation of the work. The object models follow UML and ISA-88/95 to support basic operation of FASTORY Line and FESTO Line production, which were introduced in Chapter 4.

In this chapter, the implementation of the approach outlined in Chapter 3 is presented and validated with the case studies described in Chapter 4. Among 9 object models and 86 objects defined in ISA-95, the modeller tries to provide as sufficient as possible information on industrial systems to enlarge the compatibility of the system and the standard. This is visualized by giving at least one example in most of the objects and giving complete attributes in every object. Necessary explanation and process of analysis are also added.

5.2 ISA-95 Tool

As mentioned in Chapter 2, there is a lack of visual-operating software as support phase for ISA-95's practical application. The knowledge still stays in the combination of models and attributes, which extremely increases the difficulty of the application.

As one solution to the problem, "ISA-95 Tool" assigns "order" as the core concept and information carrier functioning in Manufacturing, Operation and Control level (level 3 in ISA standard family) and Business Planning and Logistics level (level 4 in ISA standard family) [33]. The process starts when the order is received from customers and then transferred between system managers, analysts and operators. The process ends up with creating and transferring an .xml file to low-level controller.

However, systems' demand varies from factory to factory and so all models are necessary keeping the process running in a practical industrial use.

The first phase presented as a frame allows users to select models by their demands *(Figure 5.).*

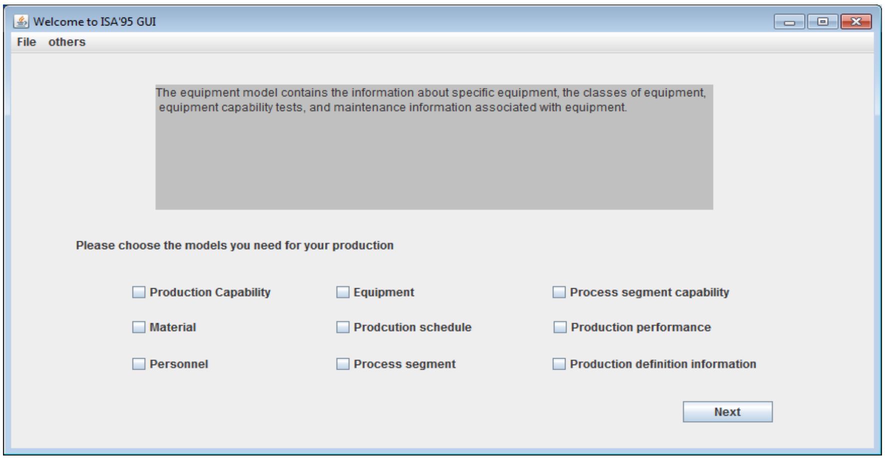

Figure 5.1 *Model-selection phase of ISA-95 Tool*

The tool will list attributes and text-fields under selected models *(Figure 5.2).* The definitions of the attributes in the 9 models come from a minimum set of industry-independent information. The attributes are extensions to the object information model defined in ISA-95.00.01 and thus are part of the definition of terms. The attributes and models define interfaces for enterprise-control system integration.

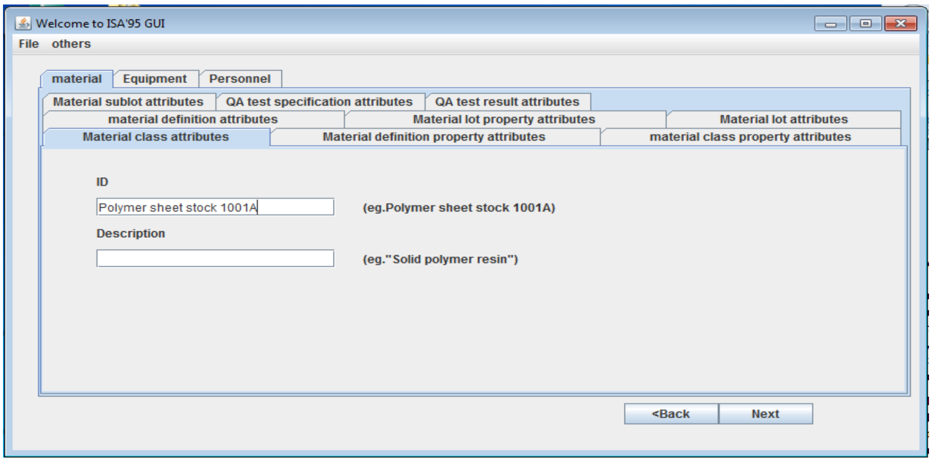

Figure 5.2 *Attributes information phase of ISA-95 Tool*

An order list with information as Order ID and production start time can be created in 3rd phase. A single cycle for all the operations in an order can be completed by pressing “Start” button (*Figure 5.3*).

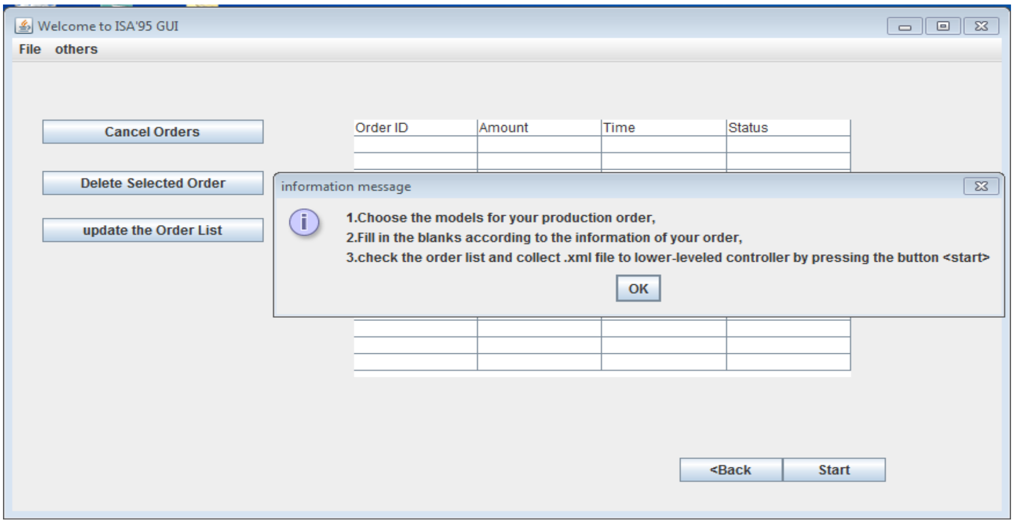

Figure 5.3 *Order-checking phase of ISA-95 Tool*

Here lists the attributes from FESTO Line that need to be put into ISA 95 tools as an example of the application of the tool.

EquipmentID	**EquipmentDescription**	**EquipmentClass**	**ClassProperties**
StackMagazine	The magazine barrel of the stack magazine holds up to 8 work pieces.	**DistributingStation**	The Distributing station separates work pieces from the Stack magazine module.
SuctionCup	A vacuum switch checks whether a work piece has been picked up.	**DistributingStation**	
ChangerModule	The Changer module is a pneumatic handling device. Work pieces are picked up using a suction cup and transferred	**DistributingStation**	
OpticalSensorDS	Senses the presence a part in the stack.	**DistributingStation**	
RecognitionModule	Material or colour identification is carried out by means of 2 proximity sensors with digital output.	**TestingStation**	The testing station determines the characteristics of the work pieces received by the previous station, in this case the Distributing station.
LiftingModuleTS	The work pieces are lifted from the sensing module to the measuring module by means of the lifting module.	**TestingStation**	
MeasuringModule	Consists of an analogue sensor for the height measurement of work pieces.	**TestingStation**	
AirCushionedSlideModule	Used to transport work pieces.	**TestingStation**	
SlideModuleDS	Used to transport work pieces.	**TestingStation**	
PicAlfaModule	Uses industrial handling components.	**HandlingStation**	The handling station is equipped
SlideModuleHS	The slide module is used to	**HandlingStation**	

	transport and store work pieces.		with a flexible two-axis handling device.
ReceptacleModule	The work pieces are inserted by the previous station into the Receptacle module.	**HandlingStation**	
RotaryIndexingTable Module	The drive of the Rotary indexing table module is operated by a DC gear motor.	**ProcessingStation**	The Processing station checks the characteristics of work pieces, machines work pieces and supplies work pieces to a subsequent station.
TestingModule	An inserted work piece is checked for correct positioning. If the hole points upwards, then the armature of the testing solenoid reaches its end position.	**ProcessingStation**	
DrillingModule	The drilling module is used to simulate the polishing of the hole of the work piece.	**ProcessingStation**	
ClampingModule	The clamping device clamps the work piece.	**ProcessingStation**	
SortingGateModule	It passes the work piece to a subsequent station.	**ProcessingStation**	
CapacitiveProximitySensor	Not applicable	**ProcessingStation**	
SlideModuleRobot	The slide module is used to transport and store work pieces. It is used as a worpiece feeder for the Retainer module.	**RobotStation**	The Robot station assemblies work pieces or separates red/metallic and black work pieces.
RetainerModule	The work pieces are inserted via a slide into the Retainer module. The work pieces are detected in the retainer by and optical reflex light sensor.	**RobotStation**	
RobotModule	Robot RV-2AJ with robot controller.- A vertical articulated arm robot is used to transport the work pieces.	**RobotStation**	
Gripper	A gripper is fitted to the robot arm. As actuator for the gripper a pneumatic parallel gripper is used.	**RobotStation**	
AssemblyRetainerModule	Work pieces are assembled in the Assembly retainer module.	**RobotStation**	
OpticalSensorRS	Used to check the orientation of the work piece body and cap.	**RobotStation**	
MagazineModule	The magazine module is used for the storing of round work pieces.	**RobotStation**	
SpringMagazineModu	By means of the Spring	**AssemblyStation**	The

le	magazine module springs are separated from a gravity-feed magazine.		Assembly station supplies work pieces for the Robot station.
SlideModuleAS	The Slide module is used to transport or store the work pieces.	**AssemblyStation**	
CapMagazineModule	Separates work pieces from a gravity-feed magazine. The cap of the work piece for assembly is transferred to a transfer point. Up to 10 caps can be stacked in the	**AssemblyStation**	
PalletModule	The Pallet module is used to provide pistons with two different diameters.	**AssemblyStation**	
HolderModule	The work pieces are inserted manually or by forward upstream station into the Holder module.	**SortingStation**	The sorting station detects the colour of incoming work pieces and deposits them into one of three levels of the rack module, depending on their colour, black, red or silver.
StorageModule	Used to identify, store and to retrieve work pieces.	**SortingStation**	
RackModule	Used for storage of symbolic work pieces.	**SortingStation**	
Ecom Mill CONCEPT 105	Used for milling task, controlled by control panel.	**MillingStation**	The milling station finishes the milling task. The process can be single or part of the production combination.
LinearAxis	Used for 3D guiding.	**MillingStation**	
ComissioningStation	Used for commissioning.	**MillingStation**	
RSRobot	RS-3SDB	**MillingStation**	
Shelf	Used for holding components.	**ASRSStation**	Automatic Storage and Retrieval System
TransportingBeam	Used for transporting within ASRS Station.	**ASRSStation**	
Conveyor Belt	Used for transporting pallet holders between station.	**Conveyor**	Used for transporting components between station.
Conveyor Pallet Holder	Used as pallet carriers.	**Conveyor**	

***Table** 4 Multi FMS Equipment Attributes*

Material	**MaterialLot**	**MaterialLot**	**Material**	**Material**	**Material**

LotID	Description	Properties	PropertiesValue	Class	ClassDescription
RedCylinder	Big Cylinder in red	PropertiesRedCylinder	In accordance with FESTO company standard	**Cylinder**	As the main body of the assembled parts.
SilverCylinder	Big Cylinder in silver	PropertiesSilverCylinder	In accordance with FESTO company standard	**Cylinder**	
BlackCylinder	Small Cylinder in black	PropertiesBlackCylinder	In accordance with FESTO company standard	**Cylinder**	
CylinderCap	As the cover of the cylinder	Properties CylinderCap	In accordance with FESTO company standard	**Cap**	As the cover of the cylinder.
Spring	Placed inside the cylinder with a piston	Properties Spring	In accordance with FESTO company standard	**Spring**	Placed inside the cylinder with a piston
BlackPiston	Placed in red/silver Cylinder	Properties BlackPiston	In accordance with FESTO company standard	**Piston**	Placed in cylinders.
MetallicPiston	Placed in black Cylinder	Properties MetallicPiston	In accordance with FESTO company standard	**Piston**	

Table 5 *Multi FMS Material Attributes*

EquipmentCapabilityTestID	EquipmentCapabilityTestDescription	MaintenanceRequest	Maintenance WorkOrder
MSTest	MillingStationTest	Not applicable	Not applicable
DSTest	DistributionStationTest	Not applicable	Not applicable
TSTest	TestingStationTest	Not applicable	Not applicable
HSTest	HandlingStationtest	Not applicable	Not applicable
PSTest	ProcessingStationTest	Not applicable	Not applicable
RSTest	RobotStationTest	Not applicable	Not applicable
ASTest	AssemblyStationTest	Not applicable	Not applicable
SSTest	StoringStationTest	Not applicable	Not applicable
ConTest	ConveyorTest	Not applicable	Not applicable

Table 6 *Multi FMS Equipment Capability Test Attributes*

5.3 A specific version of ISA-95 for FASTory GUI

Like mentioned in *Chapter 1 and Chapter 2*, FASTory GUI is a tailored realization of an approach for particular automated production system - FASTORY line described in Chapter 4.. Starting from the action flow, the operator set input by choosing radio button groups and making selection in combo boxes in GUI (*Figure 5.4*). The product segment information in accordance with the choice will be displayed in the JTable below simultaneously.

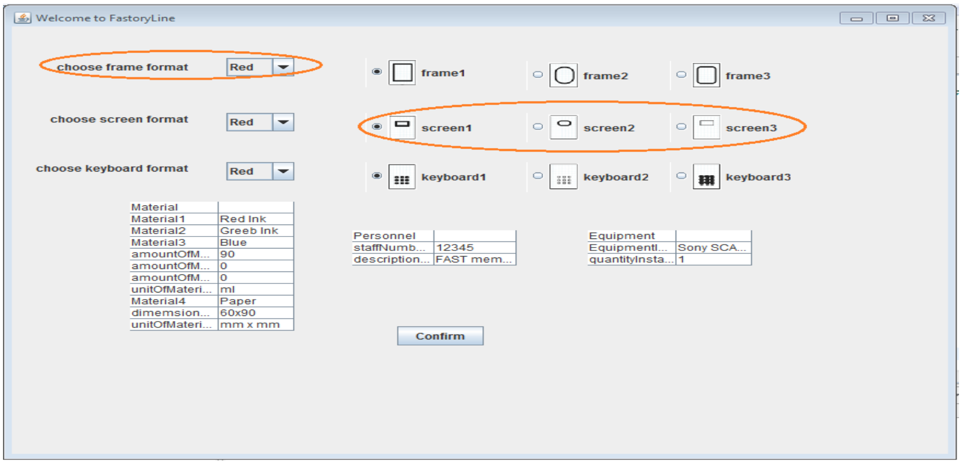

Figure 5.4 *GUI operating interface (1)*

After confirmation, the operator can check the demand of material, personnel, quipment, schedule, product from product segment (see

Figure 5.5 GUI operating interface (2)*Figure 5.5*). The operator adds orders list after the correction of the mistakes (if any).

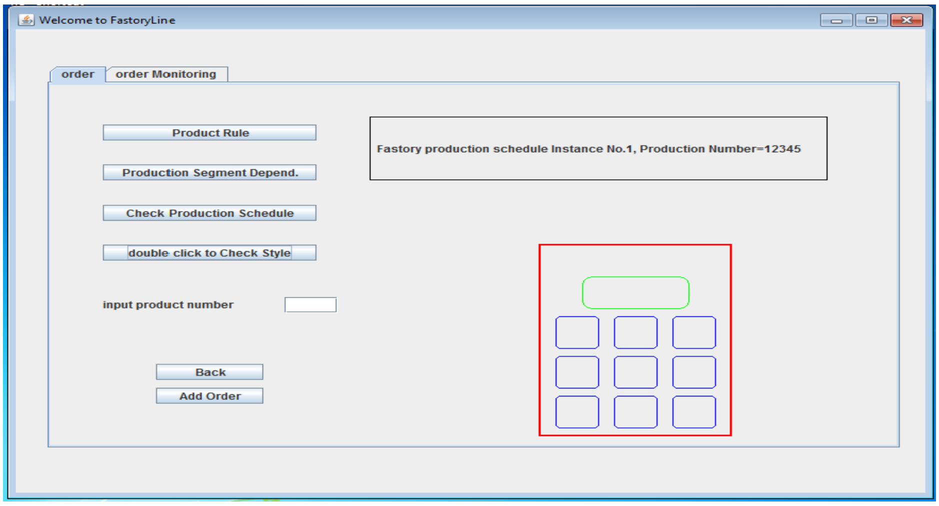

Figure 5.5 *GUI operating interface (2)*

If the order doesn’t reach the requirement, the operator can delete the unwanted order in monitoring Block (*Figure 5.6*). The operator can cancel the whole procedure by cancel of orders.

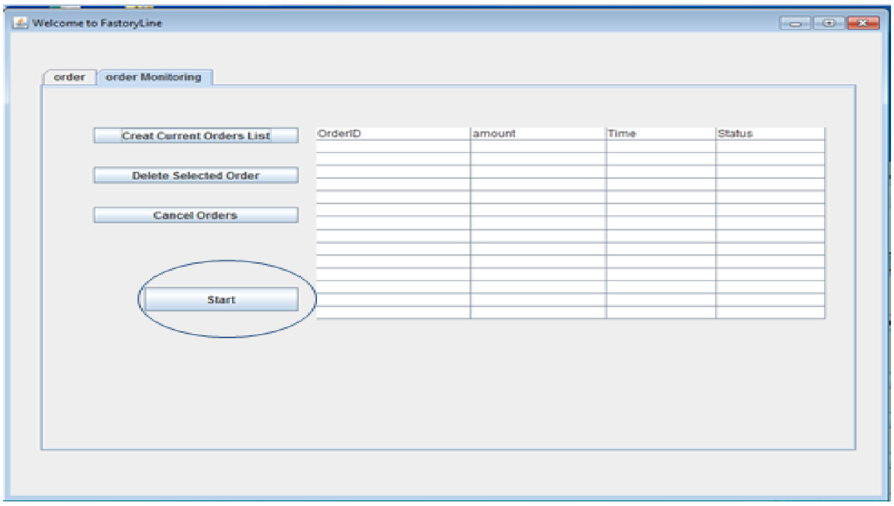

Figure 5.6 *GUI operating interface (3)*

All the functions e.g., check production rule are defined according to the 9 object models in Part 3: Approach and the entire object models refer to standards provided in ISA-95.

When all the necessary information is collected correctly, the FASTory engineer completes the order by pressing “Start” button on “order Monitoring” tab. After this, an .xml file following B2MML’s format and collecting your choices will be created and transferred to lower level.

5.4 B2MML

B2MML is an XML implementation of the ANSI/ISA-95 family of standards, known internationally as IEC/ISO 62264. B2MML consists of a set of XML schemas written using the XSD that implement the data models in the ISA-95 standard.

Companies interested in following ISA-95 for integration projects may use B2MML to integrate business systems such as ERP and supply chain management systems with manufacturing systems such as control systems and manufacturing execution systems. B2MML is a complete implementation of ISA-95.

From v02, .xsd files are available as part of the package released by WBF.

In either FASTory GUI or ISA-95 Tool, an .xml file collecting inputs will be created after the operations cycle and transferred to controllers in lower level.

The first step is done by adding values to an existing .xml file template. As mentioned, from v02 of B2MML, .xsd files are available as part of the packages released by WBF (The Organization for Production Technology). The template here is created following .xsd file format. Little changes as adding root elements to .xsd files are required if the format transformation is completed by an xml software. Part of the B2MML code is attached (*Appendix 18*) as part of the work result.

Root elements need to be added to the source code of .xsd from B2MML. Set Material.xsd file v4010 as an example, the code is available in *Appendix 18*. In SIIS as

FASTory Line and FESTO Line, not all data are in top level of importance, which means only part of information can keep the system running processes.

Another reason to reduce the amount of the information is that garbage elements, null elements and long header bring larger workload and difficulty for low controllers to collect and analyze the information. For these reasons, another scenario is considered that engineer chooses elements artificially and generate .xml file with chosen elements. An example of this has been tested on FASTory GUI (see *Appendix 19 & Appendix 20*). In the second scenario, the programming solution reduces the time needed analyzing and extracting information for files.

6. Conclusions & Future Work

The ISA-95 standard models were analyzed and extended during this thesis. The software tools were built to make use of the models that represent production systems information.

ISA-95 is an important standard for the development connecting control system and enterprises and B2MML was selected as implementation language for the standard. “ISA-95 Tool” was developed as a GUI visualizing the models and attributes from abstract concepts, putting them into practical industrial use. “FASTory GUI” is a specialized version based on “ISA-95” taking FASTory Line as a study case. It provides an example of how “ISA-95 Tool” can be extended to fit factories, enterprises in different size and types as separate solutions, though it is already sufficient and powerful enough working as an independent tool.

As mentioned in the beginning of Chapter 3, the initial goal of this thesis work is to create a solid application on analyzing information as product orders referring to ISA-95 and other materials as PERA. The B2MML serve as the information carrier and the implementation of the tool. However, the orchestration of the web services is not considered necessary in this thesis. More work related to web services can be part of the future work.

Another place for further developments and researches is that the model “production performance” could be checked after at least one single process segment. Thus an .xml file containing performance model information is needed backwardly from low-level controller to “ISA-95 Tool”. Such function can be added but some changes on the web service between the tool and the controller are needed.

Functions as importing and exporting project plan files could be added so that users can “configure once, use every now and then”. Also, some factors out of pure technology are considered here. Some make-up on interfaces helps on holding the market when the tools are put into business use.

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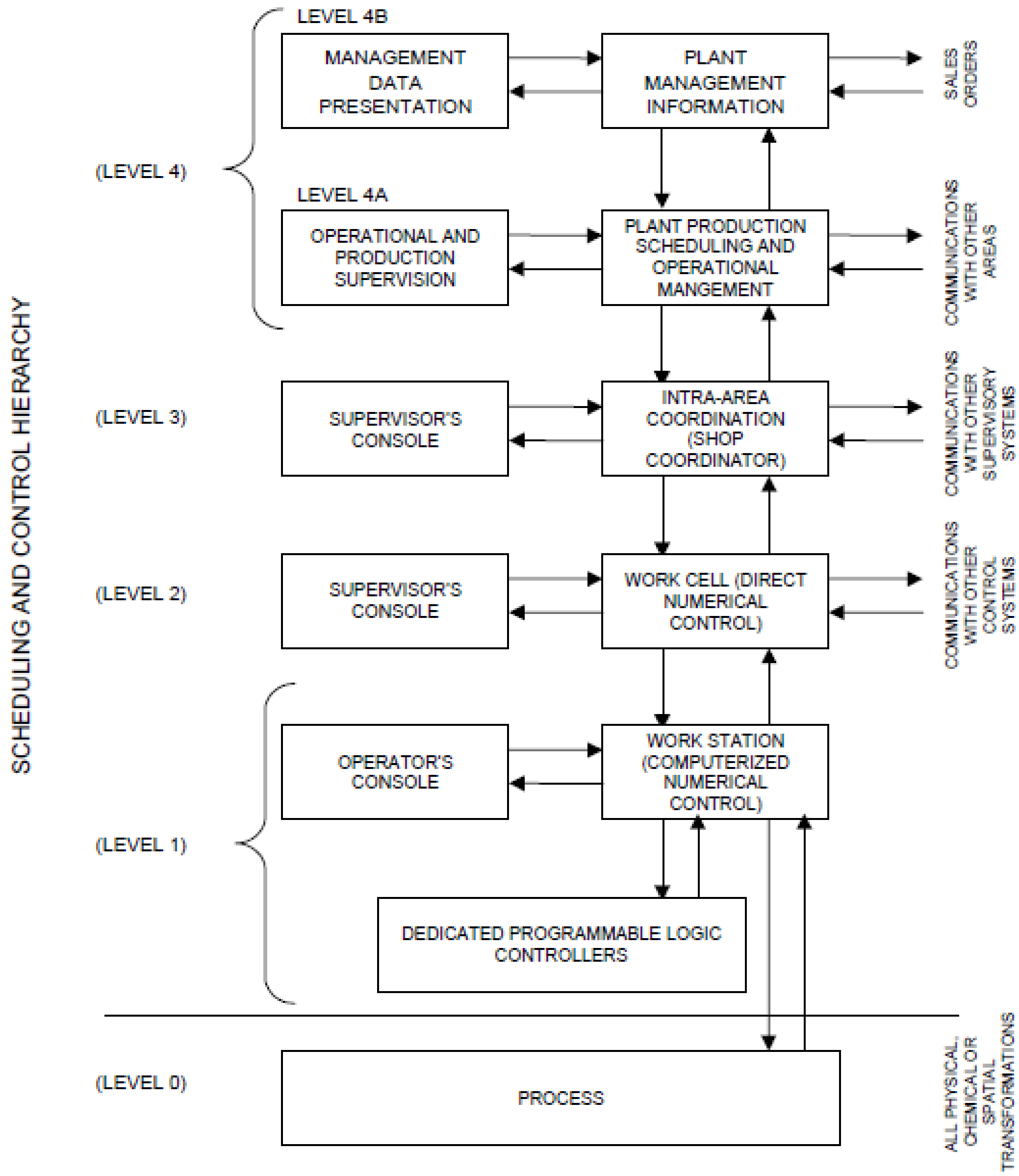
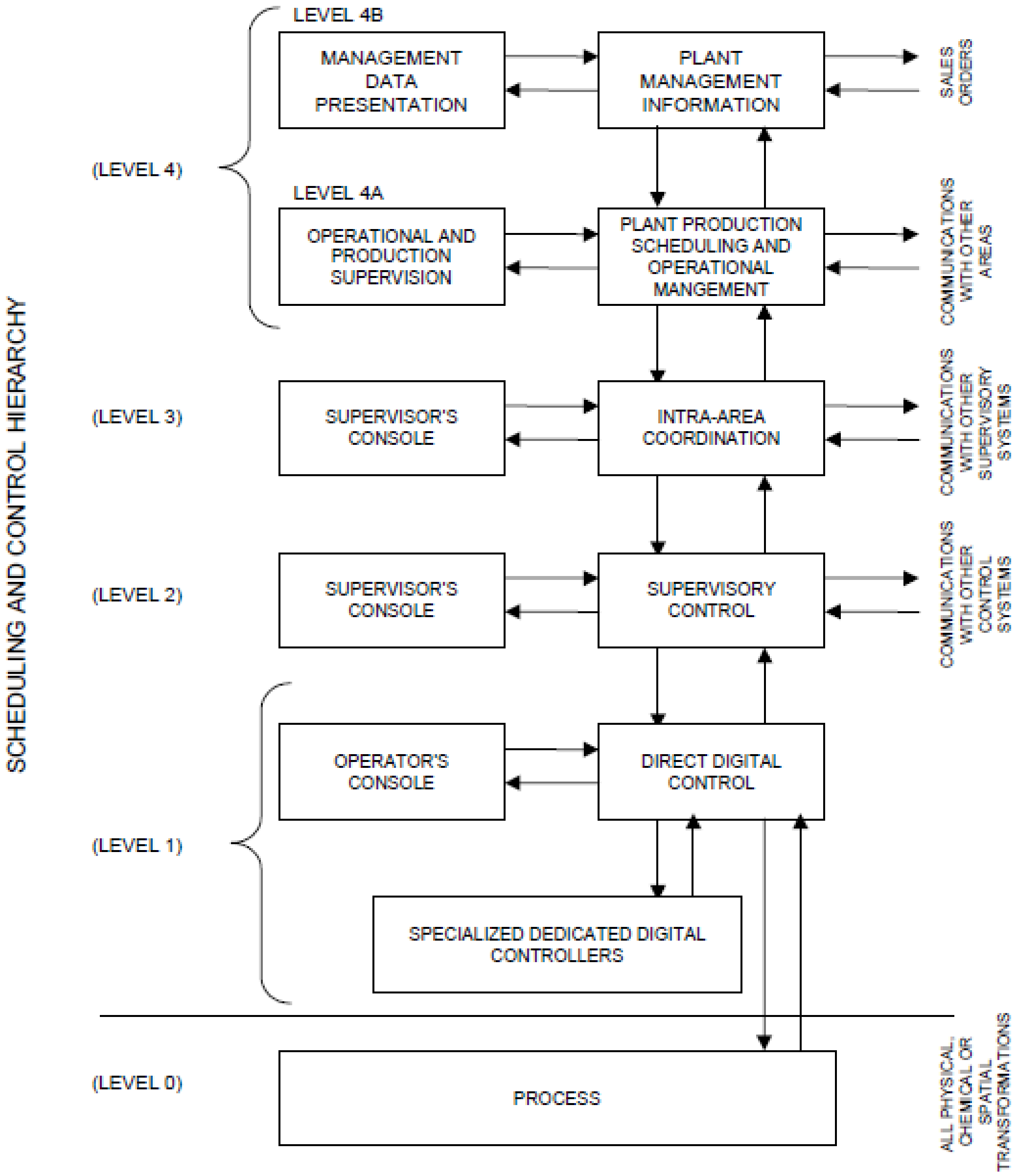
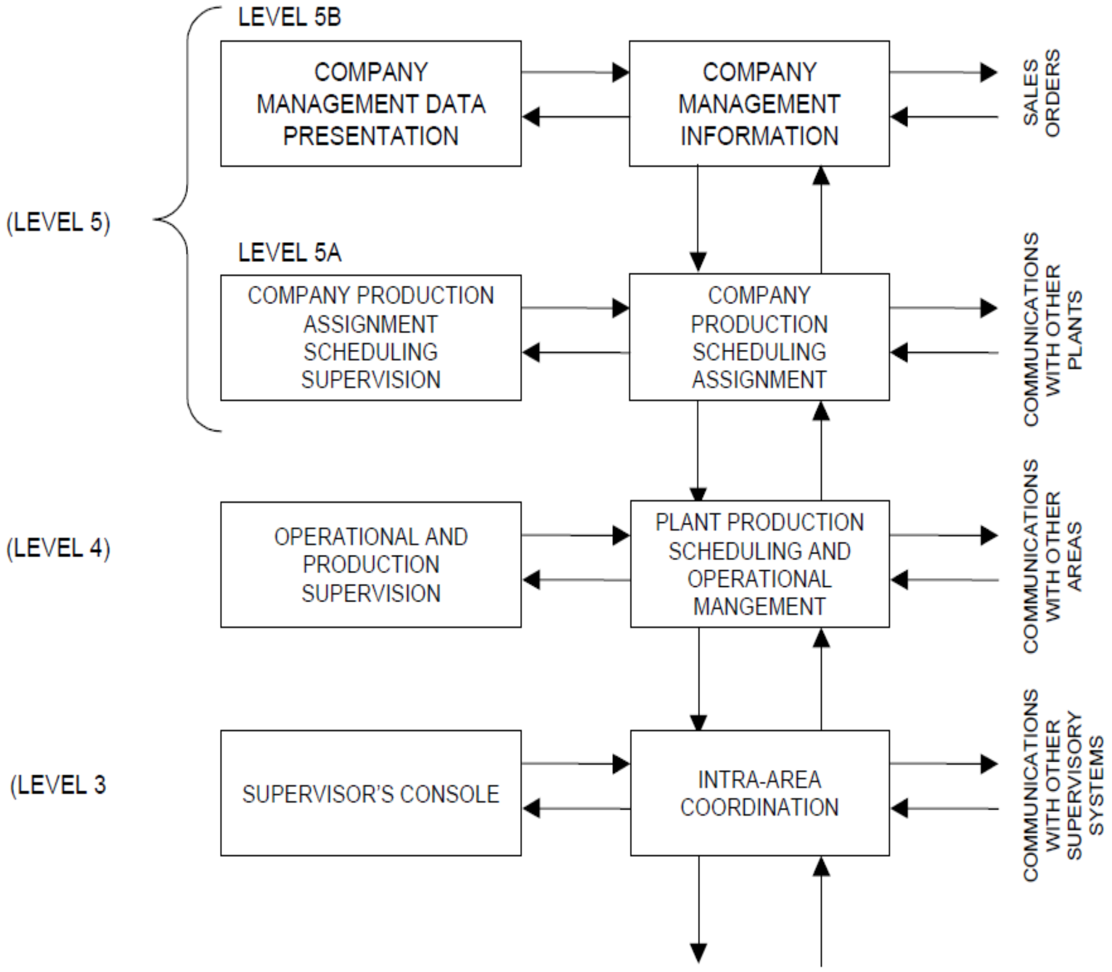
Appendix 1 : Assumed hierarchical computer control structure for a large manufacturing complex CIM (computer integrated manufacturing)



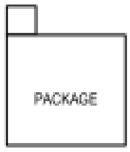
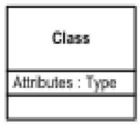
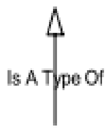
Appendix 2 : Assumed hierarchical computer control system structure for an industrial plant (continuous process such as petrochemicals)



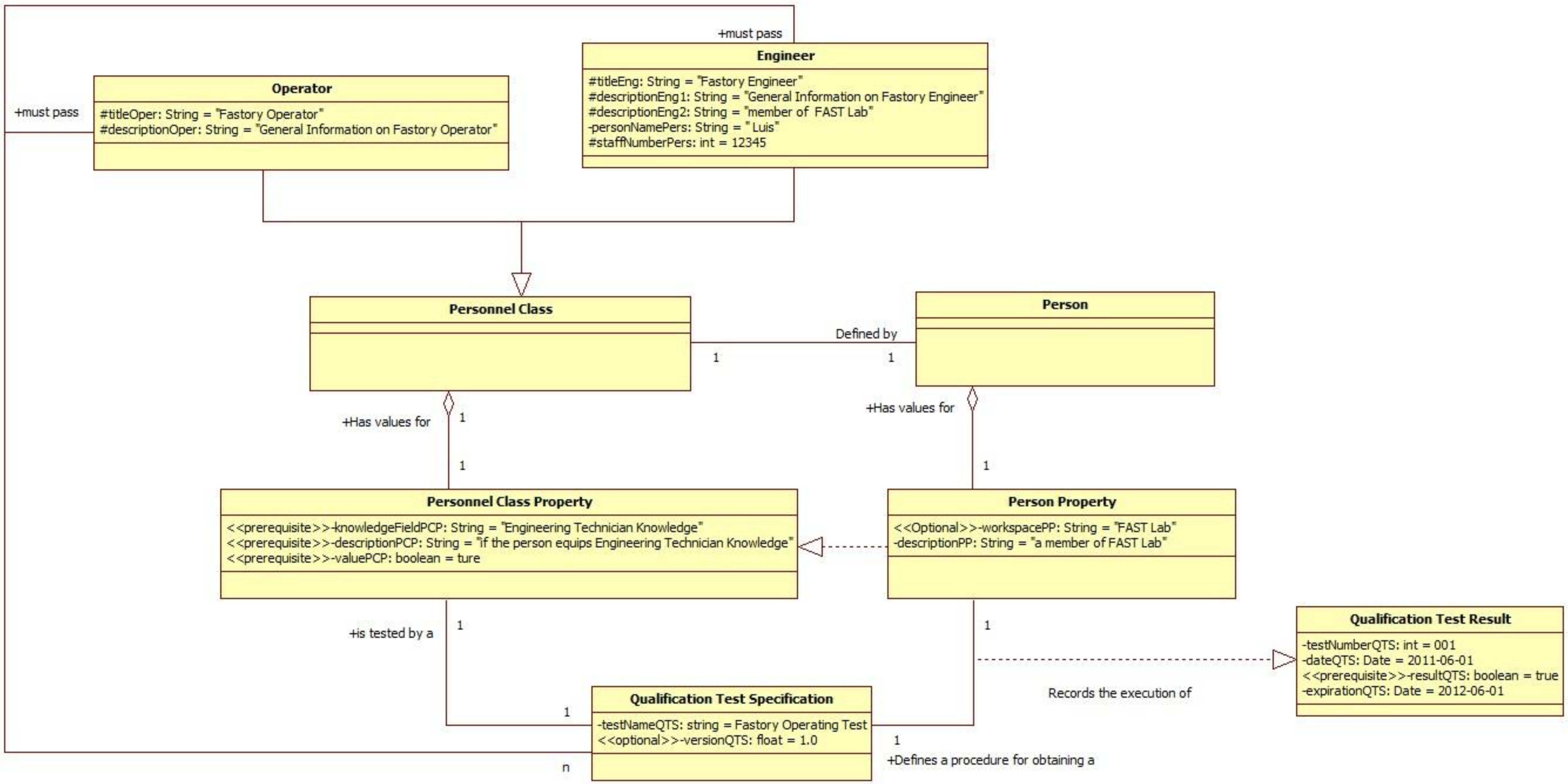
Appendix 3 : Assumed hierarchical computer control structure for an industrial company (multi-plant) to show level 5 and its relationship to the revised level 4



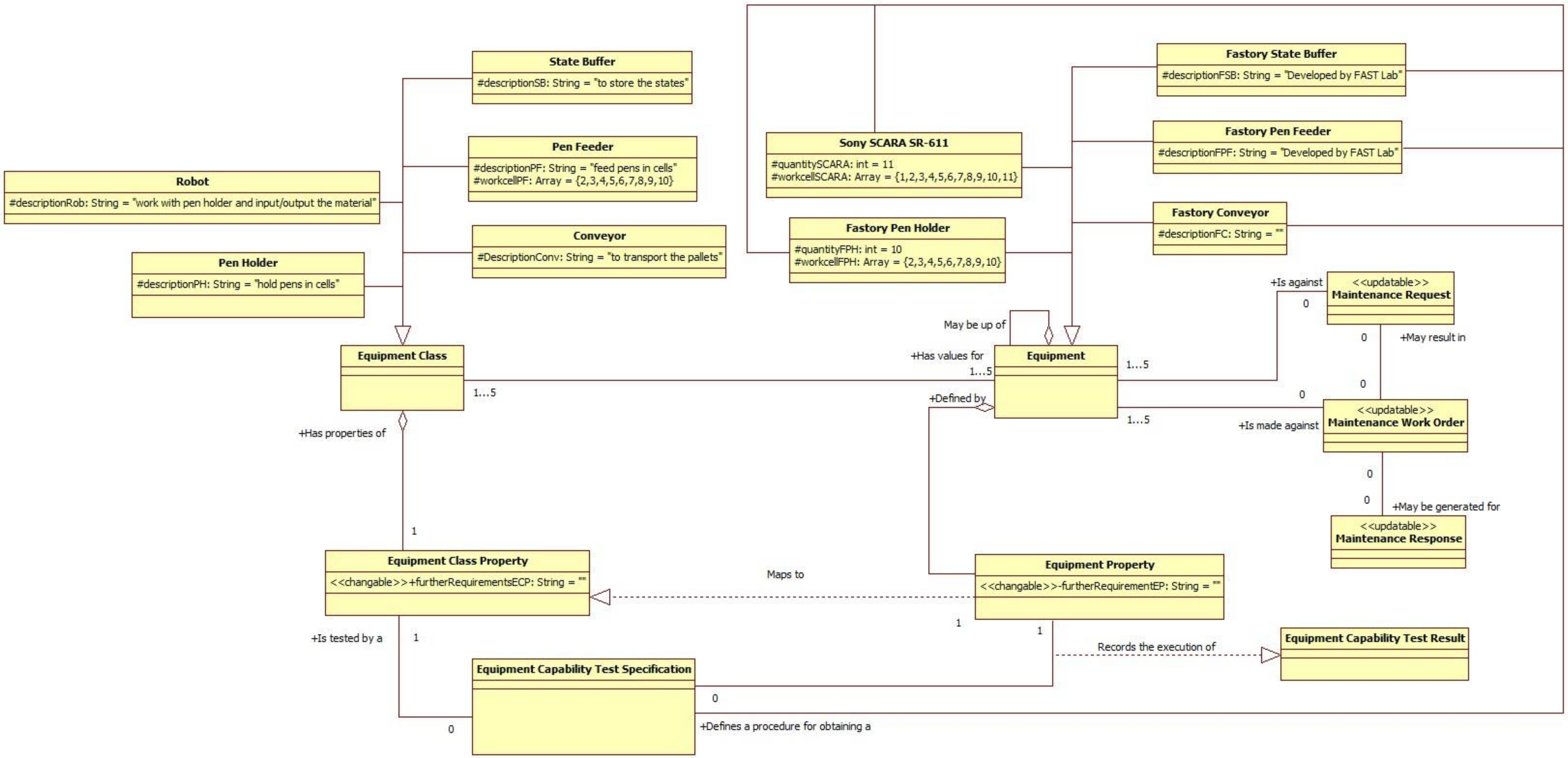
Appendix 4 : UML notation

Symbol	Definition
	Defines a package, a collection of object models, state models, use classes, and other UML models. In this document a package is used to specify an external model, such as a production rule model, or a reference to another part of the model.
	Defines a class of objects, each with the same types of attributes. Each object must be uniquely identifiable or enumerable. No operations or methods are listed for the classes. Attributes with a " - " before their name indicate attributes that are generally optional in any use of the class.
	An association between elements of a class and elements of another or the same class. Each association is identified. Can have the expected number or range of members of the subclass, when 'n' indicates an indeterminate number. For example, 0,n means that zero or more members of the subclass may exist.
	Generalization (arrow points to the super class) shows that an element of the class is a specialized type of the super class.
	Dependence (tightly bound relationship between the items) shows that an element of the class depends on an element of another class.
	Aggregation (made up of) shows that an element of the class is made up of elements of other classes.

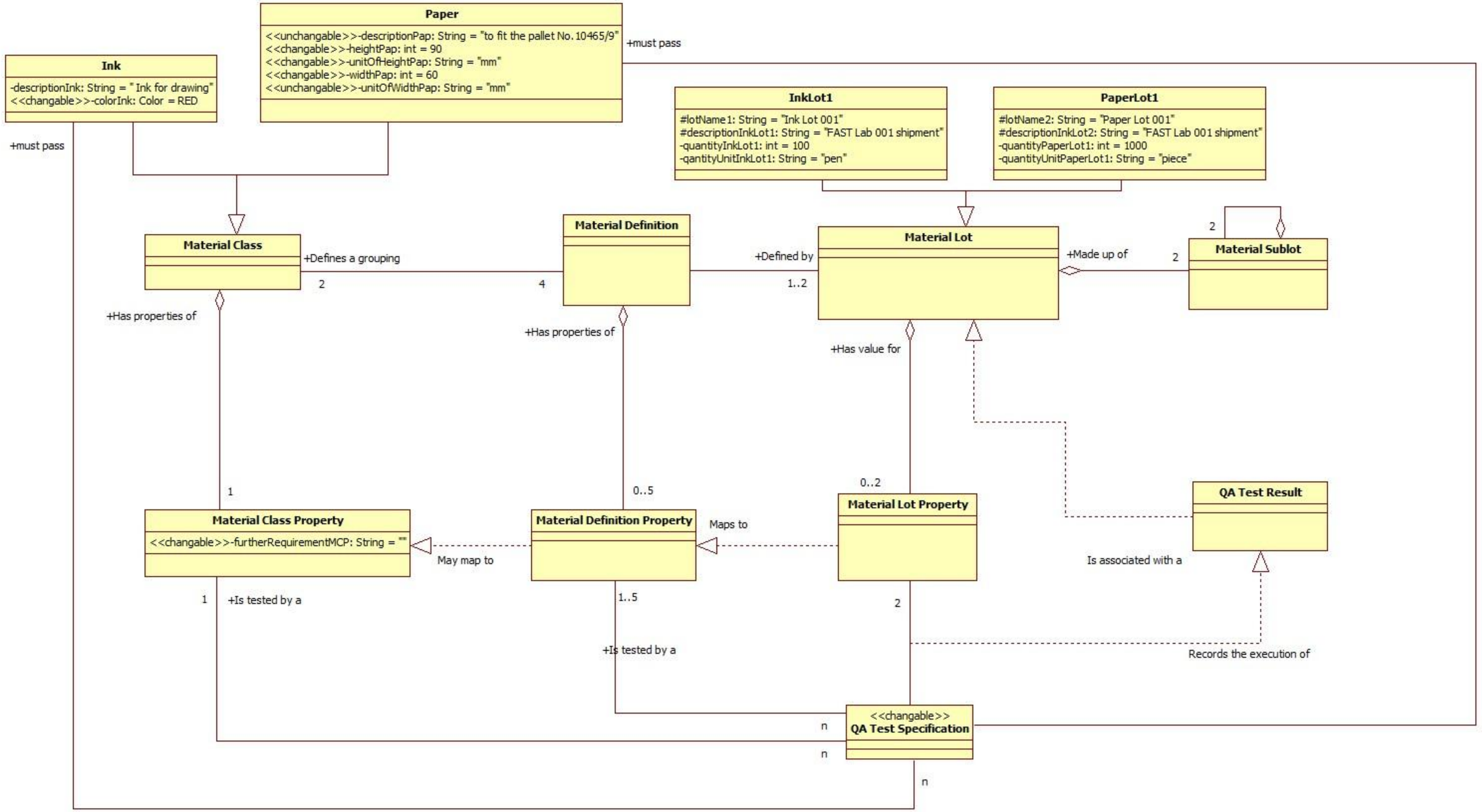
Appendix 5: Personnel model for FASTory Line



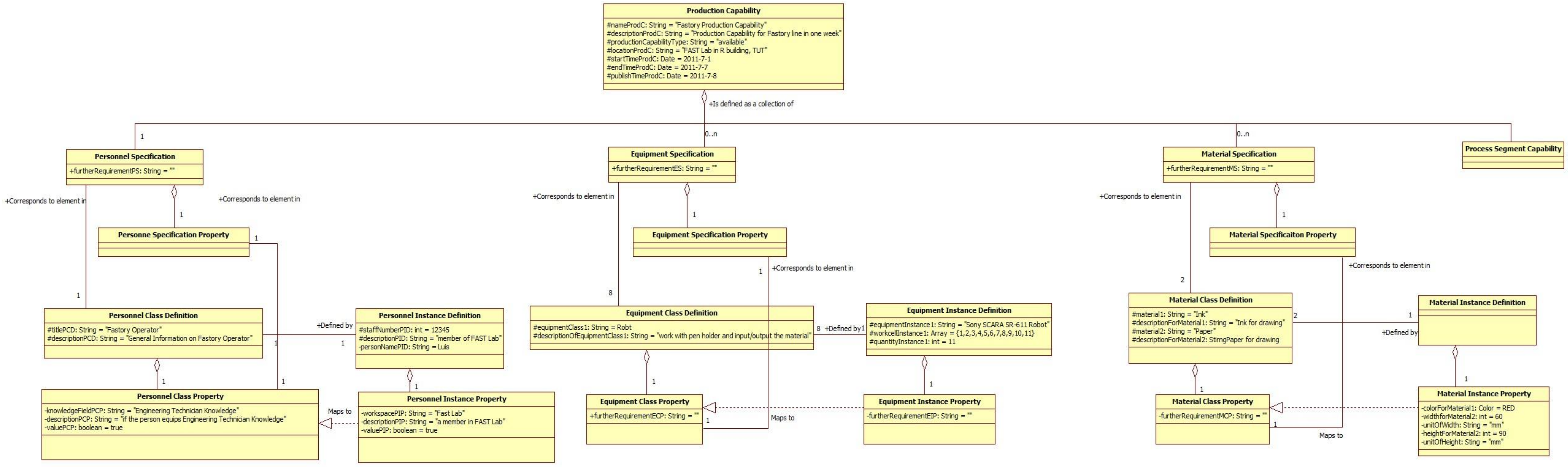
Appendix 6: Equipment Model for FASTory Line



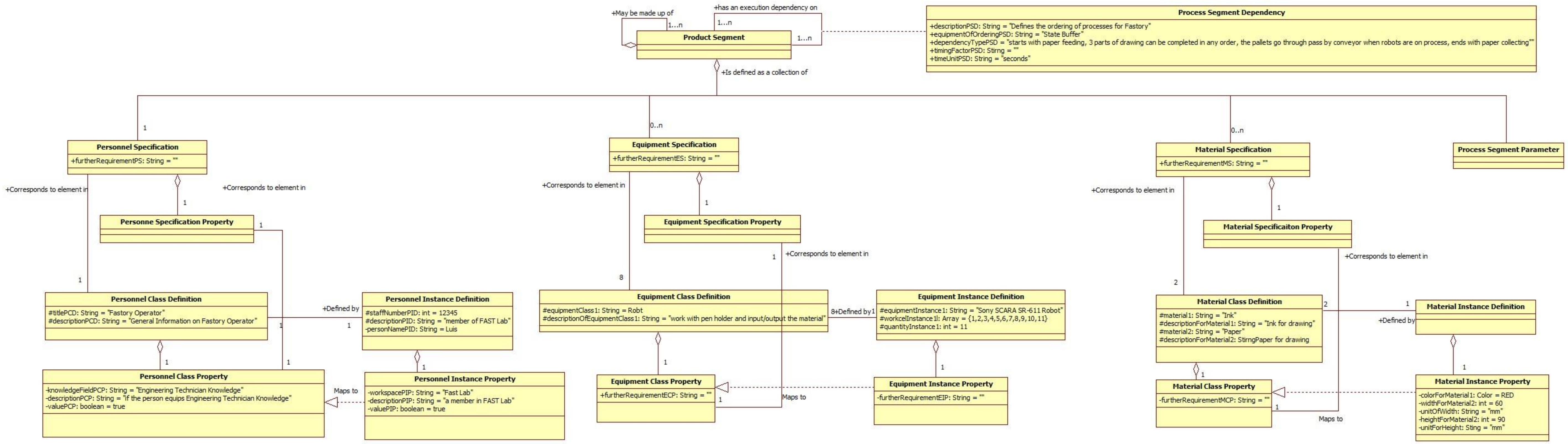
Appendix 7: Material model for FASTory Line



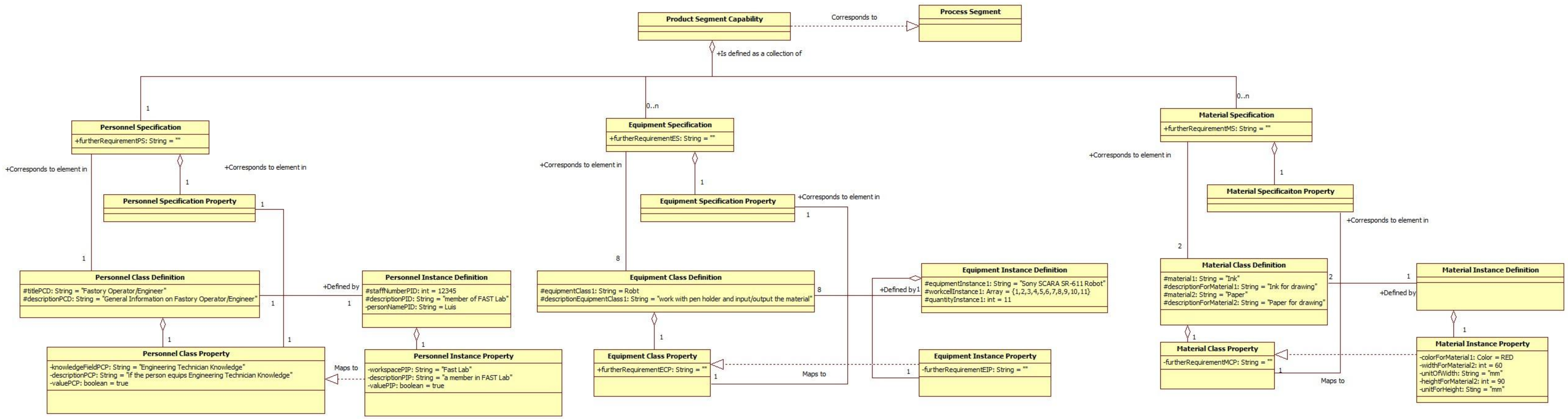
Appendix 8: Production capability model for FASTory Line



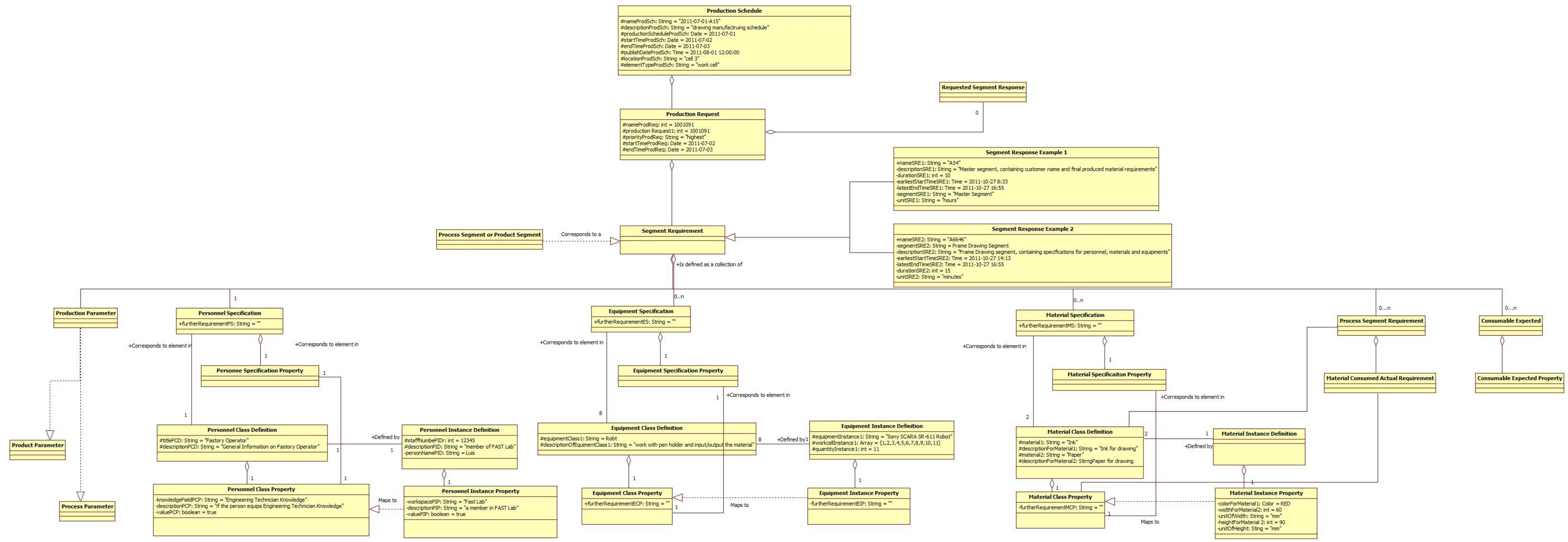
Appendix 9: Process Segment Model for FASTory Line



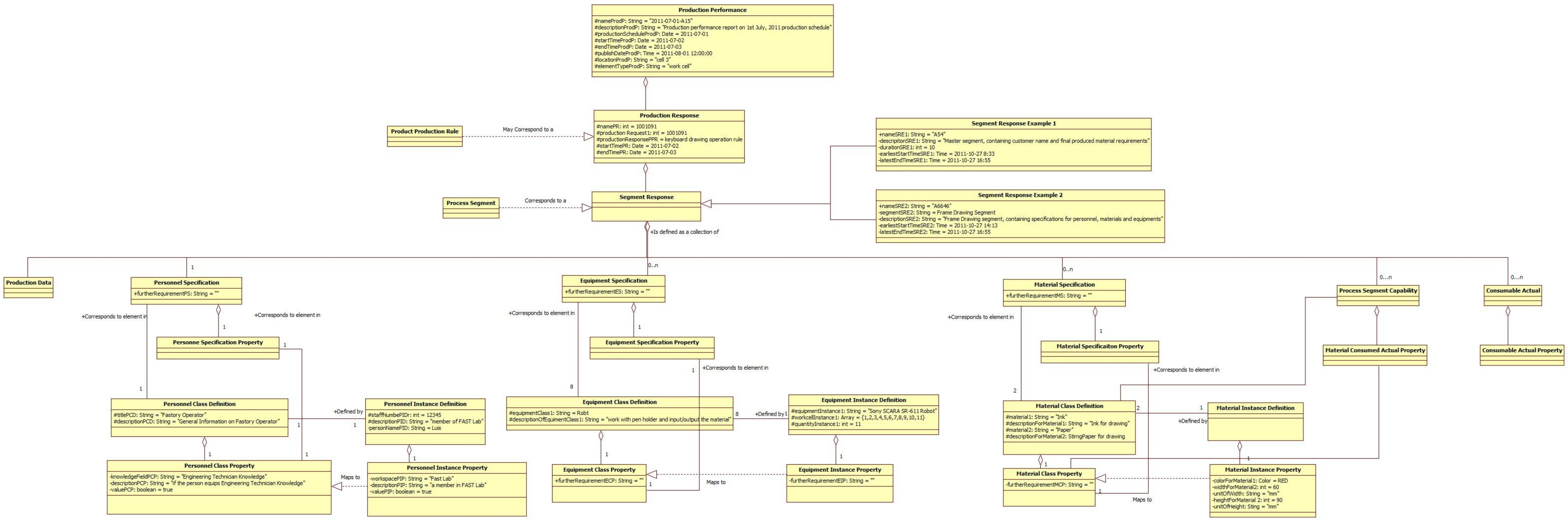
Appendix 10: Process segment capability for FASTory Line



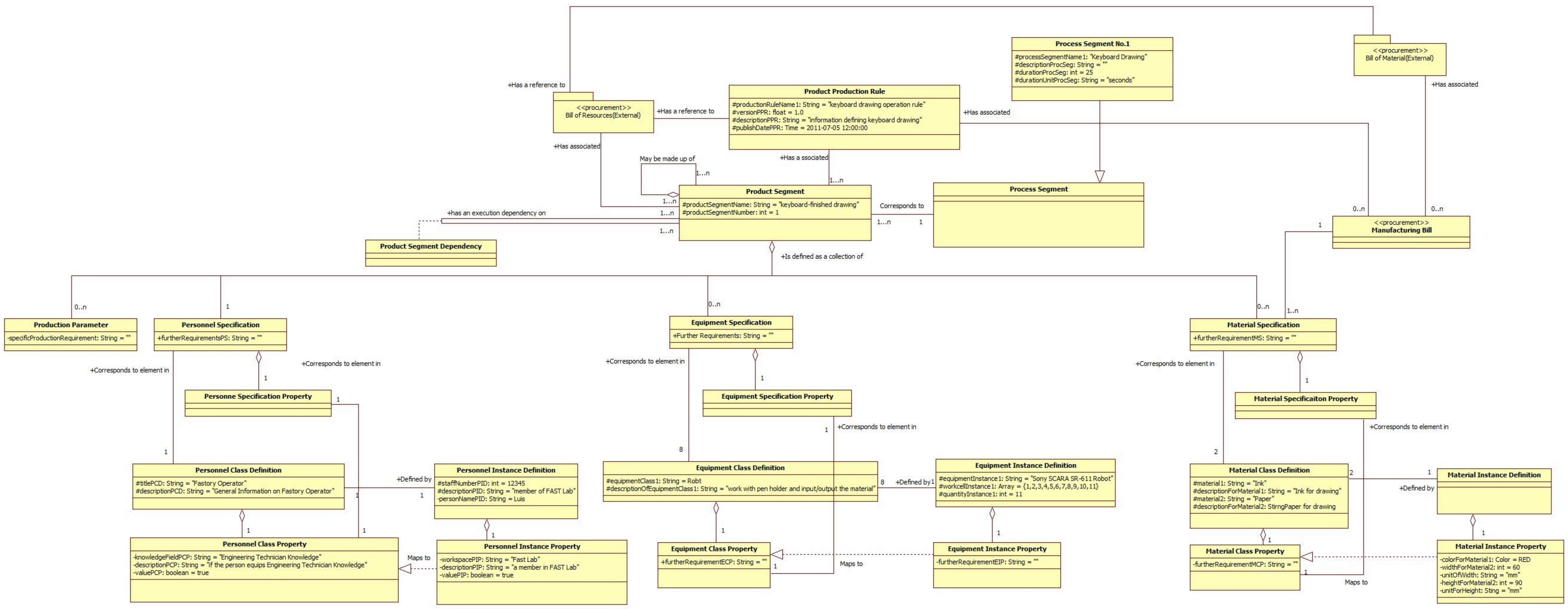
Appendix 11: Production schedule model for FASTory Line



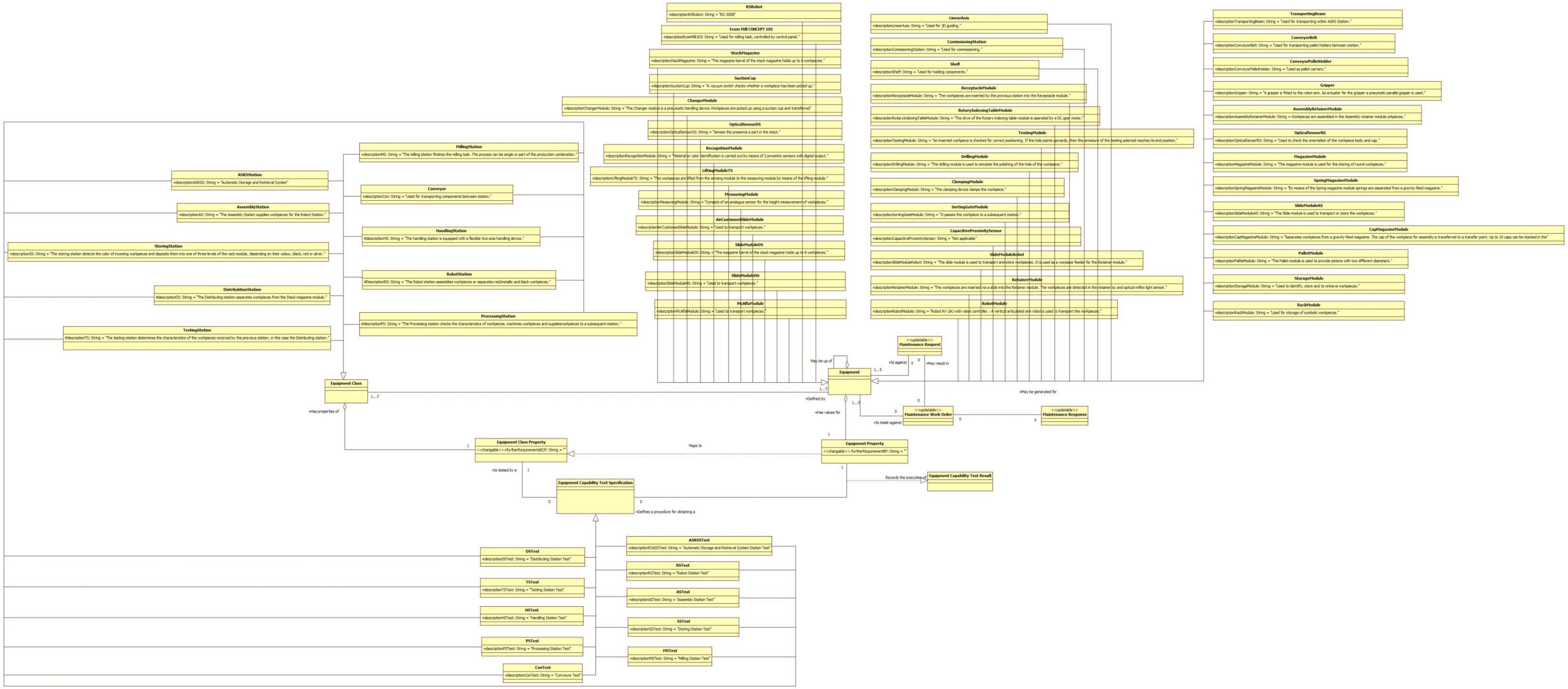
Appendix 12: Production Response Model for FASTory Line



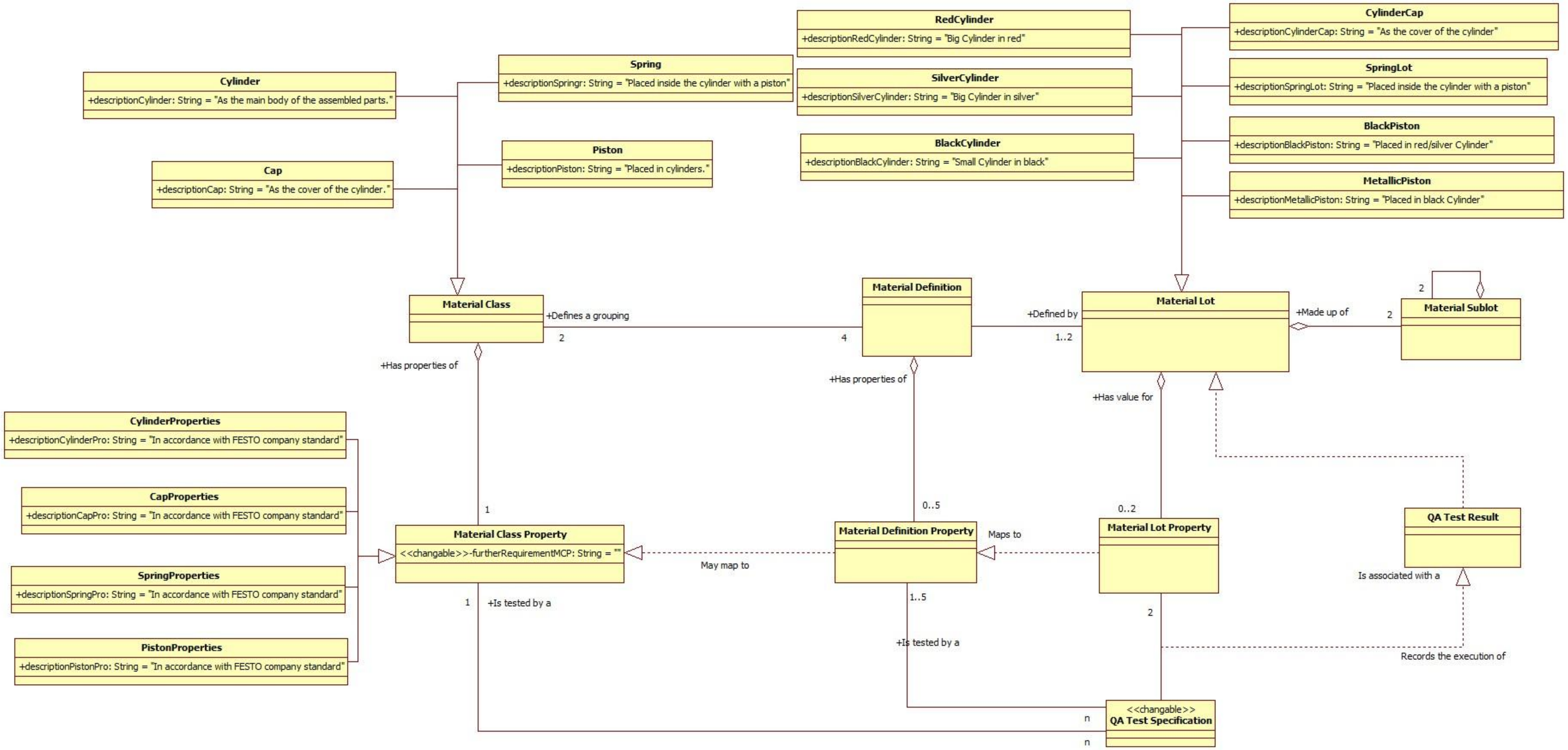
Appendix 13: Product definition model for FASTory Line



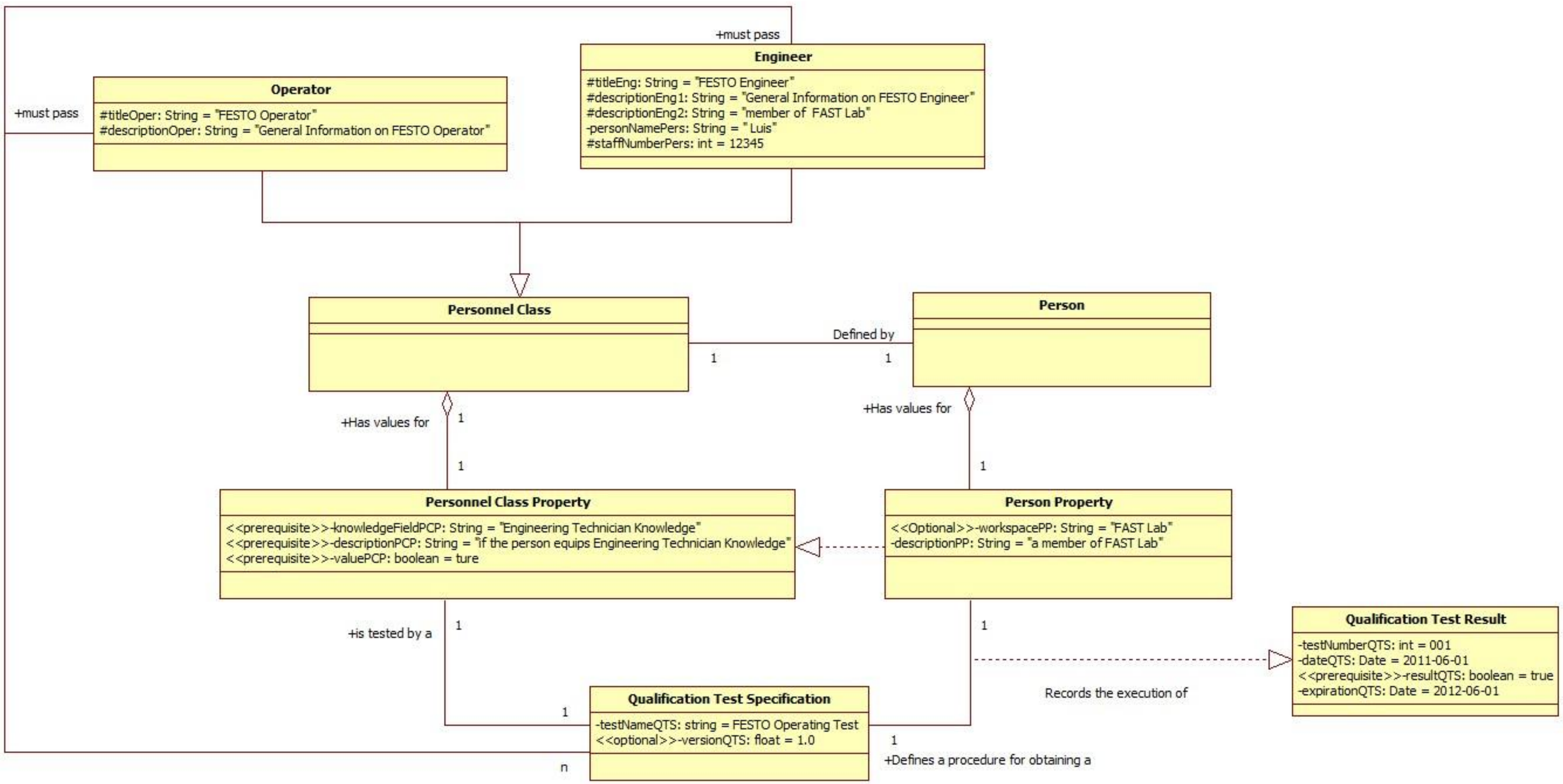
Appendix 14: Equipment Object Model for FESTO Line



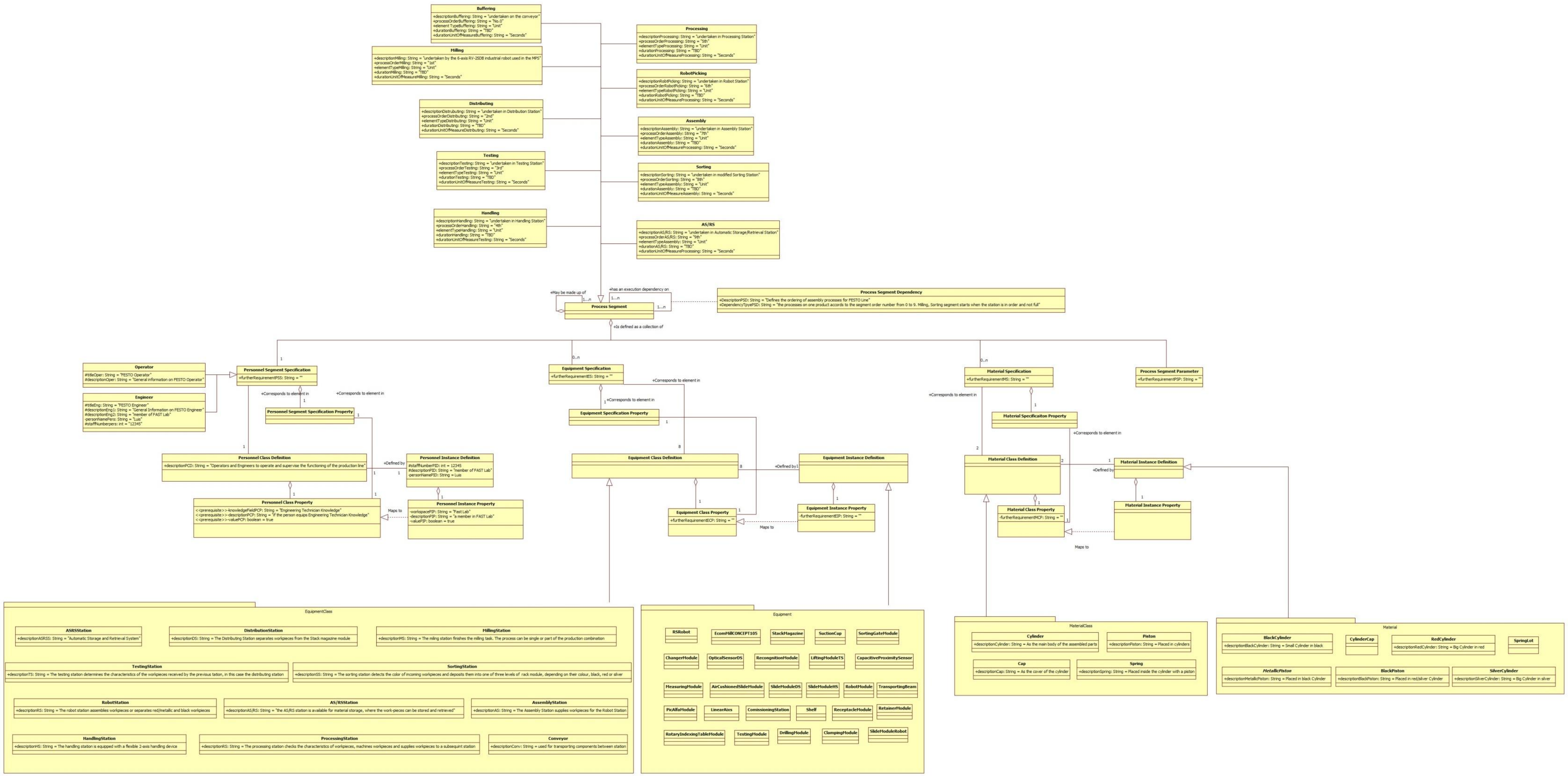
Appendix 15: Material Object Model for FESTO Line



Appendix 16: Personnel Object Model for FESTO Line



Appendix 17: Process Segment Object Model for FESTO Line



Appendix 18 : An example of root elements in B2MML file

```
<xsd:element name="root_element">
    <xsd:complexType>
        <xsd:sequence>
         <xsd:element ref="MaterialInformation" type="MaterialInformationType"/>
         <xsd:element ref="MaterialClass" type="MaterialClassType"/>
         <xsd:element ref="MaterialDefinition" type="MaterialDefinitionType"/>
         <xsd:element ref="MaterialLot" type="MaterialLotType"/>
         <xsd:element ref="QAMaterialTestSpecification"
                          type="QAMaterialTestSpecificationType"/>
         <xsd:element ref="MaterialSubLot"
                         type="MaterialSubLotType"/>
         <xsd:element ref="GetMaterialInformation"
         type="GetMaterialInformationType"/>
         <xsd:element ref="ShowMaterialInformation"
                         type="ShowMaterialInformationType"/>
        </xsd:sequence>
   </xsd:complexType>
```

Appendix 19 : An example of generated .B2MML file format

```
<?xml version='1.0' encoding='UTF-8'?>
  <root_element xsi:schemaLocation="http://www.wbf.org/xml/B2MML-V0401
  C:\Users\he\Desktop\B2MML-BatchML-V0401-Schema\B2MML-V0401-
  Material.xsd"xmlns="http://www.wbf.org/xml/B2MML-V0401"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">

        <MaterialInformation xmlns="http://www.wbf.org/xml/B2MML-V0401"/>
        <MaterialClass xmlns="http://www.wbf.org/xml/B2MML-V0401">
        <ID xmlns="http://www.wbf.org/xml/B2MML-V0401">VALUE</ID>

        </MaterialClass>
        <MaterialDefinition xmlns="http://www.wbf.org/xml/B2MML-V0401">
        <ID xmlns="http://www.wbf.org/xml/B2MML-V0401">VALUE</ID>

        </MaterialDefinition>
        <MaterialLot xmlns="http://www.wbf.org/xml/B2MML-V0401">
        <ID xmlns="http://www.wbf.org/xml/B2MML-V0401">VALUE</ID>

        </MaterialLot>
       …………
  </root_element>
```

Appendix 20 : An example of generated .B2MML file format in another scenario

---


```xml
<?xml version="1.0" encoding="UTF-8"?>
<?xml-stylesheet type="xsl" href="FASToryOrder.xsl"?>
<Orders>
  <!--An Order Catalog-->
  <Order ID="02">
        <amount>99</amount>
         <time>Tue Sep 20 12:58:58 EEST 2011</time>
    <Formats>
        <frameFormat Color="1">1</frameFormat>
         <screenFormat Color="0">0</screenFormat>
        <keyboardFormat Color="1">1</keyboardFormat>
    </Formats>
    <Materials>
      <Material sn="01">
        <ID>RedInk</ID>
         <Amount>90</Amount>
        <Unit>ml</Unit>
      </Material>
      <Material sn="02">
        <ID>GreenInk</ID>
         <Amount>0</Amount>
         <Unit>ml</Unit>
      </Material>
      <Material sn="03">
        <ID>BlueInk</ID>
        <Amount>0</Amount>
        <Unit>ml</Unit>
      </Material>
      <Material sn="04">
         <ID>Paper</ID>
        <Dimension>60 x 90</Dimension>
        <Unit>mm x mm</Unit>
      </Material>
    </Materials>
  </Order>
         <Order>
                <amount>000</amount>
                <time>0000</time>
          </Order>
</Orders>
```